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THE SYSTEM OF *CASTOR*

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With the exception of two early spectrograms of the brighter component, all the plates used in this paper were taken with the remounted Mills spectrograph, λ 4500 central. Both components are of the Sirian type, catalogued in the Harvard classifications as *A* and VIII *a*. The absorption is somewhat more complete in a_1, the fainter component, than in a_2. The number of measurable lines is accordingly somewhat greater in a_1, the average being thirty-four, as against twenty-four for a_2. Although the lines in a_2 are not so distinctly defined, yet when the proper exposure is secured, the measures seem to be somewhat more accurate on this star than on a_1. In the table given herewith are placed the lines used in in the investigation, with their adopted wave-lengths.

It was found advantageous to employ a slit rather longer than is usually the practice with the Mills spectrograph, and the exposures which gave the best plates under average atmospheric conditions were eighteen and forty-four minutes for the brighter and fainter components, respectively.

It is not to be understood that the lines marked "lacking" in a_2 do not occur, but that they are too indistinct for measurement. All lines used in this part of the spectrum of a_1 are thought to occur in a_2, although the less complete absorption in the latter star renders the fainter lines very indistinct, and for some lines seems

to leave no trace at all except on one or two plates whose exposure conditions were most favorable.

TABLE OF WAVE-LENGTHS

λ	Description	a_1	a_2	Notes
4367.839	*Ti* 2	Occasional	Faint or lacking	
74.99	*Ti* enhanced		Diff. or lacking	Gives constant negative residuals; wave-length about 4374.92
83.720	*Fe* 15			
85.548	*Fe* enhanced		Lacking	
87.007	*Ti*? 1	Rare		One or two plates only
95.201	*Ti* 3 enhanced			
99.935	*Ti Cr* 3 enhanced			
4404.927	*Fe* 10 enhanced			
15.293	*Fe* 10 enhanced			
16.985	2			
17.884	*Ti* 3 enhanced			
43.976	*Ti* 5 enhanced		Gen. poor	Rather untrustworthy
50.654	*Ti*(?) 2 enhanced		Gen. lacking	
59.301	*Fe* 3		Lacking	
64.617	*Ti* 2 enhanced	Occasional	Lacking	One plate only
66.727	*Fe* 5	Occasional	Lacking	Difficult
68.663	*Ti* 5 enhanced			
76.185	*Fe* 5		Gen. lacking	
81.400	*Mg*			Always strong
89.351	?	Poor	Occasional	
91.570	2 *Fe*? enhanced			Frequently too difficult to use
94.738	*Fe* 6	Rare	Lacking	
4501.448	*Ti*-5 enhanced			Always strong
08.455	*Fe*?-4 enhanced			
15.501	*Fe* enhanced			
20.397	*Fe*?-3 enhanced			
22.802	*Fe*			
25.314	*Fe* 5	Rare	Lacking	
28.798	*Fe* 8	Occasional	Lacking	
34.139	*Ti-Co* 6 enhanced			Generally good
41.690	*Cr* 2	Occasional	Gen. lacking	
49.642	*Fe* 2 enhanced			Strongest line in this part of the spectrum
54.211	*Ba* 8		Difficult	
56.070	*Fe* enhanced		Difficult	
58.827	*Cr*? 3			
63.939	*Ti* 4 enhanced			
72.156	*Ti*-6 enhanced			
76.512	*Ti*? enhanced		Lacking	
83.011	1	Occasional	Lacking	
84.018	*Fe* 4 enhanced			
88.381	3			
90.114			Occasional	
92.840	*Fe* 4		Rare	
4618.971	*Fe*-4d?			
29.521	*Ti-Co* 6			

The intensities in column 2 are as given in Rowland's table for the Sun. The star lines vary greatly from this scale.

α_1 *GEMINORUM*

(Fainter component; south preceding; magn. = 3.7)

The binary character of this component of *Castor* was discovered by Professor Belopolsky at Pulkova in 1896.[1] In his last paper Belopolsky has considered several hypotheses as to the orbit of this system, to which reference will be made later.

The Lick Observatory plates of this component are as follows:

No.	Plate	G. M. T.	Velocity	Notes
1.....	3492 D	1904. October 18.007	+20.5 km	
2.....	3540 B	November 9.077	−13.6	
3.....	3546 F	9.938	+30.8	
4.....	3559 D	22.043	+24.5	
5.....	3566 A	22.817	−25.3	
6.....	3571 F	23.077	−31.3	Poor plate; wt. ½
7.....	3582 D	29.056	−30.8	
8.....	3586 D	29.842	+ 3.9	
9.....	3593 B	December 6.053	+23.9	Focus poor; wt. ½
10.....	3603 D	7.072	+ 1.9	
11.....	3613 D	8.075	−27.8	
12.....	3621 B	14.014	−24.7	
13.....	3632 E	27.940	−21.5	
14.....	3637 D	1905, January 1.980	+27.6	
15.....	3641 B	2.677	−15.1	
16.....	3646 A	2.973	−29.8	
17.....	3653 C	4.965	+21.9	
18.....	3656 B	9.906	+ 9.1	
19.....	3662 C	11.013	+14.1	
20.....	3665 D	February 13.714	−13.3	Comparison weak
21.....	3674 C	20.889	+20.7	Lines broad
22.....	3685 B	25.791	+ 8.4	Focus not very sharp
23.....	3695 B	27.749	−32.6	
24.....	3698 E	27.898	−35.9	Focus poor; wt. ½
25.....	3702 A	28.662	+ 5.7	
26.....	3706 D	28.880	+18.0	
27.....	3714 E	March 1.763	+15.2	
28.....	3717 B	1.881	+ 7.2	
29.....	3725 E	5.722	−33.0	
30.....	3729 C	5.858	−31.7	
31.....	3759 B	April 2.715	+27.1	
32.....	3794 A	May 15.694	− 0.2	

Although the Lick Observatory plates cover a period of nearly seven months, it did not seem advisable to determine the period

[1] *Bulletin* of the Acad. of Sciences of St. Petersburg, December 1896; *Astrophysical Journal*, **5**, 1, 1896; *Mem. Acad. Sci., St. Petersburg*, **11**, No. 4, 1900.

from this series alone, but to use the maxima and minima secured by Belopolsky in the years 1896–1899, in connection with the present series. From these a period of 2.928285 days was adopted, which satisfies my observations very well. This value cannot be very much in error, and any attempt to correct it in the least-square solution would be meaningless, without a much more extended series of observations. Accordingly no term for the correction to the period was included in the solution.

With this value of the period a preliminary orbit was derived by the method of Lehmann-Filhés,[1] giving the following set of elements:

PRELIMINARY ELEMENTS

Period = 2.928285 days
T = J. D. 2416827.969
$\omega = 92^\circ.695$
$e = 0.08$
$K = 31.7$
$\mu^\circ = 122^\circ.939$
Velocity of system = −0.80 km

From these elements differential coefficients were computed which, when rendered homogeneous, gave the following equations of condition:

	δV	δT	δK	$\delta\omega$	δe	u
1....	$+1.000x$	+0.6943	$+0.685z$	$-0.805u$	$+1.000v$	$-0.114=0$
2....	+1.000	−0.692	−0.350	+0.858	+0.639	−0.431
3....	+1.000	−0.237	+0.952	+0.212	−0.572	+0.351
4....	+1.000	+0.496	+0.841	−0.615	+0.875	−0.337
5....	+1.000	+0.587	−0.791	−0.697	−0.977	+0.141
6....	+0.707	+0.041	−0.708	−0.103	−0.122	+0.213
7....	+1.000	−0.165	−0.984	+0.116	+0.330	+0.300
8....	+1.000	−0.720	+0.134	+0.910	−0.214	+0.101
9....	+0.707	−0.375	+0.505	+0.436	−0.667	+0.366
10....	+1.000	+1.000	+0.051	−1.079	+0.160	+0.262
11....	+1.000	−0.488	−0.784	+0.546	+0.915	−0.532
12....	+1.000	−0.567	−0.674	+0.662	+0.942	−0.631
13....	+1.000	+0.618	−0.767	−0.726	−0.990	+0.901
14....	+1.000	+0.377	+0.906	−0.494	+0.713	−0.082
15....	+1.000	+0.824	−0.547	−0.920	−0.895	+0.757
16....	+1.000	+0.259	−0.962	−0.366	−0.577	+0.356
17....	+1.000	+0.492	+0.844	−0.610	+0.871	−1.000
18....	+1.000	−0.705	+0.256	+0.885	−0.432	+0.450
19....	+1.000	+0.831	+0.521	−0.931	+0.919	−0.396
20....	+1.000	−0.693	−0.343	+0.861	+0.628	−0.399

[1] *Astronomische Nachrichten*, **136**, 17, 1894.

	δV	δT	δK	$\delta\omega$	δe	u
21....	$+1.000x$	$+0.630y$	$+0.743z$	$-0.745u$	$+0.984v$	$-0.507=0$
22....	+1.000	−0.694	+0.315	+0.868	−0.530	−0.186
23....	+1.000	−0.017	−1.004	−0.060	−0.007	−0.002
24....	+0.707	−0.191	−0.670	+0.177	+0.397	−0.879
25....	+1.000	−0.711	+0.214	+0.896	−0.358	−0.064
26....	+1.000	−0.607	+0.580	+0.731	−0.877	+0.114
27....	+1.000	+0.786	+0.582	−0.890	+0.967	−0.614
28....	+1.000	+0.936	+0.324	−1.025	+0.662	−0.567
29....	+1.000	−0.219	−0.968	+0.184	+0.451	−0.381
30....	+1.000	−0.412	−0.859	+0.439	+0.823	−0.903
31....	+1.000	+0.292	+0.942	−0.405	+0.568	−0.498
32....	+1.000	−0.727	+0.024	+0.920	−0.011	−0.052

In the above equations

$$x=\delta V$$
$$y=[1.9028]\delta T$$
$$z=\delta K$$
$$u=[1.5011]\delta\omega$$
$$v=[1.5164]\delta e$$

Log "unit error"=0.6064

The resulting normal equations were:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,d]$	$[a\,e]$	$[a\,u]$
$+30.500x$	$+0.797y$	$-0.737z$	$-0.920u$	$+5.730v$	$-4.175=0$
	$+11.150$	$+2.656$	-13.114	$+2.422$	$+0.351$
		$+14.941$	-2.836	$+2.701$	-1.358
			$+15.509$	-2.967	-0.324
				$+15.508$	-8.761
					$+7.513$

The solution gave:

$$\delta V'=-0.14 \text{ km}$$
$$\delta T'=+0.029 \text{ days}$$
$$\delta K'=-0.102$$
$$\delta\omega'=+2^\circ.508$$
$$\delta e'=-0.0702$$

whence the elements

I

$$\text{Period}=2.928285$$
$$T=\text{J. D. } 2416827.998$$
$$e=0.0098$$
$$\mu^\circ=122^\circ.939$$
$$\omega=95.203$$
$$K=31.598$$
$$V=-0.94 \text{ km}$$

The sum of the squares of the weighted residuals has been reduced from 122.6 to 37.6. All the changes in the elements secured from the solution are small, with the exception of that for the eccentricity, which is reduced from 0.08 to 0.01. The result is that the terms of the second order are not negligible, and there is a lack of agreement between the change in the residuals secured by computing an ephemeris from these elements and by substituting the values of the unknowns directly in the equations of condition. This lack of agreement amounts in several cases to 0.3 km. A second solution therefore became necessary. This solution was based on the ephemeris secured from Elements I. The differential coefficients, when reduced to homogeneity, form the following equations of condition:

	δV	δT	δK	$\delta\omega$	δe	u
1....	$+1.000x$	$+0.774y$	$+0.629z$	$-0.787u$	$+0.997v$	$+0.561=0$
2....	+1.000	−0.878	−0.416	+0.900	+0.807	+0.167
3....	+1.000	−0.175	+0.983	+0.169	−0.435	+0.257
4....	+1.000	+0.612	+0.787	−0.626	+0.948	+0.216
5....	+1.000	+0.706	−0.707	−0.718	−0.999	−0.751
6....	+0.707	+0.154	−0.690	−0.163	−0.362	+0.115
7....	+1.000	−0.039	−1.000	+0.030	−0.012	+0.654
8....	+1.000	−0.954	+0.133	+0.981	−0.177	+0.223
9....	+0.707	−0.435	+0.546	+0.442	−0.701	+0.126
10....	+1.000	+0.100	+0.060	−1.008	+0.212	+0.342
11....	+1.000	−0.502	−0.858	+0.506	+0.836	+0.093
12....	+1.000	−0.637	−0.755	+0.646	+0.971	+0.034
13....	+1.000	+0.731	−0.682	−0.743	−0.991	+0.379
14....	+1.000	+0.506	+0.859	−0.521	+0.833	+0.517
15....	+1.000	+0.884	−0.469	−0.894	−0.776	+0.257
16....	+1.000	+0.422	−0.906	−0.436	−0.827	−0.104
17....	+1.000	+0.608	+0.789	−0.623	+0.945	−0.769
18....	+1.000	−0.926	+0.273	+0.952	−0.446	+0.539
19....	+1.000	+0.878	+0.475	−0.890	+0.887	+0.019
20....	+1.000	−0.882	−0.408	+0.903	+0.797	+0.130
21....	+1.000	+0.723	+0.686	−0.737	+0.019	−0.011
22....	+1.000	−0.906	+0.339	+0.930	−0.565	−0.494
23....	+1.000	+0.137	−0.991	−0.149	−0.361	−0.141
24....	+0.707	−0.125	−0.696	+0.120	+0.189	$-\mathring{1}.000$
25....	+1.000	−0.938	+0.224	+0.964	−0.354	−0.152
26....	+1.000	−0.747	+0.633	+0.763	−0.955	−0.375
27....	+1.000	+0.845	+0.531	−0.857	+0.941	−0.245
28....	+1.000	+0.955	+0.298	−0.964	+0.646	−0.480
29....	+1.000	−0.108	−0.995	+0.100	+0.130	−0.238
30....	+1.000	−0.381	−0.922	+0.381	+0.652	−0.595
31....	+1.000	+0.426	+0.901	−0.441	+0.718	−0.175
32....	+1.000	−0.962	+0.007	+0.990	+0.073	+0.175

The factors for homogeneity in this second set of equations are:

$$x=\delta V$$
$$y=[1.8391]\delta T$$
$$z=\delta K$$
$$u=[1.4997]\delta\omega$$
$$v=[1.4997]\delta e$$

Log "unit error" = 0.4298

The resulting normal equations are:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,d]$	$[a\,e]$	$[a\,u]$
$+30.500x$	$+0.8855y$	$-1.096z$	$-0.897u$	$+3.896v$	$-0.504=0$
	$+15.288$	$+2.372$	-15.593	$+2.215$	-0.188
		$+14.616$	-2.379	$+2.931$	$+0.920$
			$+15.900$	-2.269	$+0.200$
				$+15.335$	$+0.120$
					$+5.232$

The solution of these equations gives:

$$\delta V''=-0.04 \text{ km}$$
$$\delta T''=+0.059 \text{ days}$$
$$\delta K''=+0.164$$
$$\delta\omega''=+7^\circ.313$$
$$\delta e''=+0.00001$$

FINAL ELEMENTS

Period = 2.928285 days	
T = J. D.2416828.057	± 0.042 days
$e=0.01$	± 0.0066
$\mu^\circ=122^\circ.939$	
$\omega=102^\circ.516$	$\pm 5^\circ.120$
$K=31.76$	± 0.22
$V=-0.98$ km	± 0.15 km
$a \sin i=1{,}279{,}000$ km	
$[pvv]$ equations = 37.3	
$[pvv]$ ephemeris = 37.6	

An ephemeris computed with circular elements gave $[pvv]=40.6$.

The second solution is satisfactory. In the annexed table are given the residuals computed from these elements, and also the comparison between the change in the residuals secured from the

ephemeris and that resulting from direct substitution in the equations of condition.

No.	O.−C.	Equat.−Eph.	No.	O.−C.	Equat.−Eph.
1.....	+1.49	−0.02	17.....	−2.13	+0.01
2.....	+0.50	−0.01	18.....	+1.35	−0.02
3.....	+0.60	0.00	19.....	+0.01	+0.03
4.....	+0.52	+0.02	20.....	+0.55	+0.05
5.....	−1.87	+0.03	21.....	−0.07	0.00
6.....	+0.67	+0.01	22.....	−1.45	+0.03
7.....	+1.99	−0.01	23.....	−0.15	+0.01
8.....	+0.52	+0.02	24.....	−3.57	0.00
9.....	+0.40	−0.01	25.....	−0.50	−0.02
10.....	+0.95	0.00	26.....	−1.14	+0.03
11.....	+0.43	0.00	27.....	−0.71	+0.02
12.....	+0.25	−0.01	28.....	−1.30	0.00
13.....	+1.17	+0.02	29.....	−0.41	+0.01
14.....	+1.33	+0.01	30.....	−1.41	+0.01
15.....	+0.80	−0.02	31.....	−0.55	−0.02
16.....	−0.07	+0.03	32.....	+0.41	+0.01

The probable error of a single plate is ± 0.79 km.

The observations, together with the velocity-curve, are platted in Fig. 1.

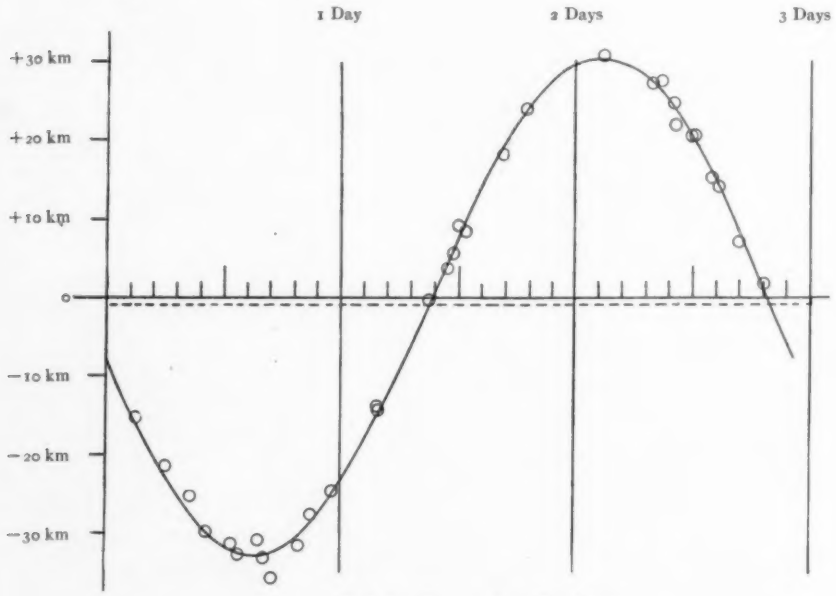


FIG. 1.—Velocity-Curve of α_1 *Geminorum*

The radius of the small circles represents the probable error of a plate. The dotted line represents the velocity of the center of mass of the system.

The only other published spectrographic observations of a_1 *Geminorum* known to the writer are the 118 made by Professor Belopolsky. For completeness they are given here, with the Julian Day of Greenwich Mean Time, and the velocity reduced to kilometers.

Jul. Day G. M. T.		Velocity	Jul. Day G. M. T.		Velocity
1894	2412926.31	+21.2 km	1897	2414224.45	+ 1.1 km
	30.28	− 5.8		29.43	+14.1
1896	3560.35	−27.4		30.43	+ 6.1
	79.37	+20.6		41.41	+31.5
	97.35	+21.7		90.46	−15.4
	3605.37	+ 1.4	1898	4292.47	−25.0
	9.38	+18.8		4310.40	−25.5
	12.34	+11.6		11.43	+26.3
	13.34	−33.8		18.45	− 3.2
	14.34	+ 1.4		19.40	−29.3
	15.25	+16.2		21.40	− 5.0
	16.28	−45.5		38.41	+15.3
	17.29	− 0.8		42.39	−34.1
	27.28	+ 1.0		64.26	+15.0
	28.24	−37.8		65.26	− 6.5
	30.24	+ 2.9		74.29	−18.0
	33.30	− 9.5		75.29	−20.0
	35.25	+26.4		76.29	+21.7
	43.25	−18.5		77.28	−20.8
	48.30	−25.9		91.26	+14.0
	49.27	+ 1.9		93.26	+ 5.9
	50.28	+28.9		94.26	+ 8.2
	51.28	−45.0		95.25	−36.8
	53.28	+22.9		95.28	−37.2
	57.28	−40.1		96.33	+22.8
	58.28	+ 8.8		4403.29	− 4.6
	61.26	+ 7.5		4.27	−32.7
	64.27	+16.2		5.27	+22.7
	67.37	+17.8		8.27	+25.5
	69.31	−31.4		9.27	−10.2
	70.31	+20.6		11.27	+31.2
	72.33	−16.5		12.27	−13.5
	74.37	−17.4		14.28	+31.5
	76.32	+34.7		4612.47	−25.4
1897	4021.28	+ 2.7	1899	74.40	+14.5
	22.28	+31.5		79.38	−29.2
	24.27	+ 7.8		79.41	−28.3
	25.28	+ 8.3		79.43	−28.1
	28.28	+13.1		83.37	+19.9
	30.28	+ 7.7		83.39	+22.9 *
	31.27	+ 4.9		83.42	+25.2

*The means of the bracketed measures were used by Professor Belopolsky.

Jul. Day G. M. T.		Velocity	Jul. Day G. M. T.		Velocity
1899	2414690.34	− 7.5km	1899	2414721.23	+ 8.6km
	90.36	− 0.7		21.31	+12.8
	90.38	− 6.8		22.22	+19.8
	90.41	−11.4		22.24	+ 6.8
	92.38	+27.1		24.22	+ 6.2
	92.40	+36.8		24.25	+16.8
	92.42	+26.3		27.30	+19.8
	95.33	+35.3		29.32	−27.7
	95.36	+24.6		34.23	− 5.1
	95.38	+29.3		34.26	− 3.3
	4709.33	− 4.2		40.24	−13.6
	9.38	+ 6.0		40.26	−11.7
	9.40	+ 1.5		54.25	+24.6
	16.39	+11.6		57.27	+21.2
	16.41	+17.3		57.38	+21.2
	16.44	+ 8.4		59.31	+ 7.4
	19.23	+17.4		61.31	−28.1
	20.29	−35.3			
	20.30	−31.7			

This extended series has been of great value in determining the period of a_1 by comparison with the Lick Observatory plates. They were made, however, in the early days of spectrographic velocity determinations, so that naturally the standard of accuracy is much lower than is now attained. These plates have been investigated by Dr. Belopolsky in his paper, "Bearbeitung der in Pulkova erhaltenen Spectrogramme von dem Spectral-Doppelstern a_1 *Geminorum.*"[1]

Dr. Belopolsky separated the plates into three groups, and tested a number of different sets of elements. He considers it probable that there is a rotation of the line of apsides. The elements which give the smallest sum of the squares of the residuals are as follows: (Belopolsky's tenth hypothesis, *loc. cit.*, p. 83):

BELOPOLSKY'S ELEMENTS

$V = -4.1$ km
$K = 33.43$
$e = 0.12$
Period $= 2.934050$ days
$\omega = 82°$ at the epoch 1896, Jan. $0^d.0$
$\Delta\omega = 0°.239726$ per day
Period of rotation of line of apsides $= 1502$ days
$[vv] = 2450$
Probable error of a plate, series of 1899 $= \pm 2.45$ km
Probable error of a plate for entire series $= \pm 3.41$ km

[1] *Mém. de. l'Acad. Imp. des Sciences de St. Petersburg*, 11, No. 4, 1900.

Dr. Belopolsky states that he does not regard the observational data as sufficient for definitive decision as to whether the assumed change in the orbital elements is real or not. The sum of the squares of the residuals for a circular orbit is not very much in excess of that for an elliptical orbit. From the present solution, it is evident that the orbit is nearly a circle. The greatest effect of a rotation of the line of apsides of the present orbit, eccentricity of 0.01, will

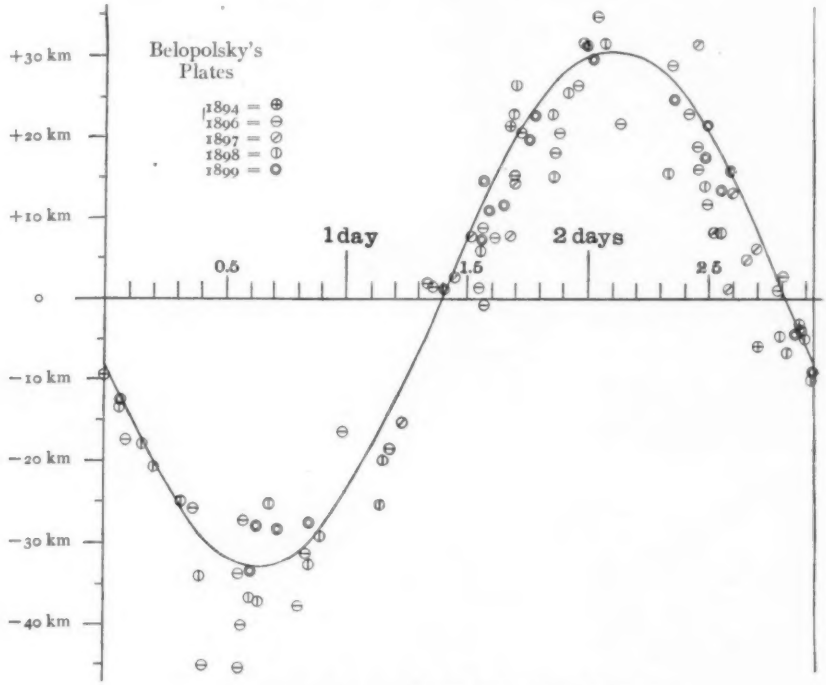


FIG. 2.—Pulkova observations of α_2 *Geminorum*

be but ± 0.3 km in the radial velocity. This cannot be detected with certainty by present methods in stars of this spectral type. The assumption of any rotation of the line of apsides must accordingly be definitely abandoned for the present.

In Fig. 2 are plotted the Pulkova observations on the velocity-curve derived from my final elements. The constant difference between the Pulkova and Lick Observatory plates shown in the figure amounts to about 3 km. Such is the uncertainty in the orbit of the visual system of *Castor* that no safe conclusion can be reached

as to the variation in the relative velocities of a_1 and a_2 in the nine years which intervened between the earlier plates of the Pulkova series and those secured at Mount Hamilton, but this difference is certainly very small and entirely insufficient to account for the difference in position of the two velocity-curves. If we accept Doberck's recent orbit with period of 347 years, the difference of the radial velocities for 1896.4 and 1904.9 will be but 0.4 km. Belopolsky's published observations for 1899 are in general the mean of several plates. These observations are much more accurate than his earlier ones, and it will be seen that they fall, as a rule, fairly close to the Lick Observatory curve.

The radii of the small circles in Fig. 2 are not equal to the probable errors of a plate, as in the other diagrams given in this paper.

a_2 *GEMINORUM*

(Brighter component; north following; mag. = 2.7)

The variation in the radial velocity of this component of *Castor* was discovered by the writer in October 1904.[1] The observations used in this discussion are given in the accompanying table. They include all the Lick Observatory plates, except two taken under poor conditions, which are so weak as to be worthless.

No.	Plate	Date G. M. T.	Velocity*	Notes
1.....	555 D	1897, November 18.975	+ 1.1 km	Poor plate
2.....	2063 C	1901, March 31.740	+17.3	Very poor; wt. ½
3.....	3465 E	1904, September 28.025	+ 2.9	
4.....	3539 A	November 9.053	+17.7	
5.....	3545 E	9.913	+15.9	
6.....	3558 C	22.015	+ 4.4	
7.....	3565 F	22.791	+ 0.9	
8.....	3570 E	23.056	− 1.4	
9.....	3581 C	29.025	+12.4	
10.....	3585 C	29.819	+ 9.5	
11.....	3592 A	December 6.025	+19.0	
12.....	3602 C	7.042	+17.4	
13.....	3612 C	8.049	+12.7	
14.....	3620 A	13.986	− 3.4	Focus poor; wt. ½
15.....	3627 C	26.941	+12.4	
16.....	3631 D	27.915	+ 9.1	
17.....	3636 C	1905, January 1.955	+ 9.5	
18.....	3640 A	2.652	+18.2	Weak plate; wt. ½
19.....	3647 B	2.994	+17.2	
20.....	3650 B	3.951	+16.1	

*The velocities for plates 1, 2, 3, 4, 9, 14, 15, 16, 30, and 31 are the weighted means of two separate measures of the same plate. The weights are determined by the number of lines used.

[1] *Publications A. S. P.*, **17**, 24, 1905; *Lick Obs. Bulletin* No. 70, 1905.

No.	Plate	Date G. M. T.		Velocity*	Notes
21.....	3652 B	1905, January	4.938	+11.2km	
{	3655 A		9.875	− 8.5 }	Comparison poor
{	3658 D		10.072	− 9.0 }	" "
22.....	Mean		9.974	− 8.7	Wt. 1
{	3661 B		10.997	+ 5.8 }	
{	3663 D		11.049	+ 6.4 }	Wt. 2
23.....	Mean		11.023	+ 6.1	
{	3673 B	February	20.850	+ 9.1 }	
{	3675 D		20.932	+ 8.1 }	
24.....	Mean		20.891	+ 8.6	Wt. 2
25.....	3678 A		24.626	− 5.2	Weak plate; wt. ½
{	3679 A		25.610	− 6.4 }	Over-exposed
{	3680 B		25.625	− 6.2 }	
26.....	Mean		25.618	− 6.3	Wt. 2
27.....	3684 A		25.757	− 5.0	Comparison weak
28.....	3688 A		25.956	− 1.3	
{	3691 E		26.605	+16.4 }	
{	3692 F		26.621	+17.5 }	
29.....	Mean		26.613	+16.9	Wt. 2
30.....	3699 A		27.927	+16.0	
31.....	3707 F		28.910	+14.7	
32.....	3713 D	March	1.738	+ 9.7	
33.....	3718 C		1.909	+ 8.4	
34.....	3720 F		2.609	+ 5.9	
{	3721 E		3.603	+ 4.6 }	Weak toward violet
{	3722 F		3.620	+ 4.2 }	
35.....	Mean		3.612	+ 4.4	Wt. 2
{	3723 C		5.654	− 4.6 }	
{	3724 D		5.676	− 5.0 }	
{	3730 A		5.886	− 5.8 }	
36.....	Mean		5.735	− 5.1	Wt. 3
37.....	3734 B		6.718	− 8.3	
38.....	3737 D		6.838	− 6.4	
{	3743 C		7.656	+14.6 }	
{	3744 D		7.676	+13.8 }	
39.....	Mean		7.666	+14.2	Wt. 2
40.....	3758 A	April	2.726	− 6.2	

*The velocities for plates 1, 2, 3, 4, 9, 14, 15, 16, 30, and 31 are the weighted means of two separate measures of the same plate. The weights are determined by the number of lines used.

A preliminary orbit was computed by the method of Lehmann-Filhés. This was tested and changed until it satisfied the observations fairly well. The adopted preliminary elements are as follows:

PRELIMINARY ELEMENTS

Period = 9.21898 days

T = J. D. 2416746.370

$\omega = 265.^{\circ}350$

$K = 13.65$

$e = 0.50$

$V = +6.20$ km

$\mu = 39.^{\circ}04987$

An ephemeris was computed from these elements and made the basis for the derivation of the differential coefficients. The equations of condition, in their homogeneous form, are:

No.	δV	δT	$\delta\mu$	δK	$\delta\omega$	δe	n
1.....	$+1.000x$	$-0.975y$	$-1.000z$	$-0.240u$	$+0.987v$	$-0.293w$	$-1.000=0$
2.....	+0.707	+0.076	+0.040	+0.607	+0.029	−0.421	−0.237
3.....	+1.000	+0.118	0.000	−0.240	−0.321	+0.292	−0.038
4.....	+1.000	+0 108	−0.002	+0.859	+0.041	−0.594	−0.102
5.....	+1.000	+0.120	−0.002	+0.619	−0.169	−0.644	+0.688
6.....	+1.000	+0.110	−0.003	−0.151	−0.301	+0.175	+0.161
7.....	+1.000	+0.124	−0.003	−0.368	−0.298	+0.436	−0.156
8.....	+1.000	+0.128	−0.003	−0.446	−0.277	+0.515	−0.791
9.....	+1.000	+0.115	−0.003	+0.443	−0.255	−0.500	+0.145
10.....	+1.000	+0.111	−0.003	+0.222	−0.312	−0.271	+0.140
11.....	+1.000	−0.035	+0.001	+0.956	+0 385	+0.081	−0.118
12.....	+1.000	+0.019	−0.004	+0.769	−0.059	−0.669	+0.393
13.....	+1.000	+0.116	−0.004	+0.486	−0.235	−0.550	−0.086
14.....	+0.707	−0.376	+0.013	−0.566	+0.542	−0.667	+0.511
15.....	+1.000	+0.113	−0.004	+0.363	−0.278	−0.430	+0.677
16.....	+1.000	+0.110	−0.004	+0.107	−0.327	−0.132	+0.764
17.....	+1.000	−0.398	+0.037	+0.280	+0.965	+0.715	−0.301
18.....	+0.707	−0.036	+0.002	+0.674	+0.288	+0.095	−0.371
19.....	+1.000	+0.066	−0.003	+0.939	+0.199	−0.347	−0.952
20.....	+1.000	+0.121	−0.005	+0.698	−0.117	−0.672	+0.215
21.....	+1.000	+0.115	−0.005	+0.423	−0.259	−0.491	−0.420
22.....	+1.000	+0.079	−0.004	−1.020	+0.198	+0.271	−0.538
23.....	+1.414	−1.414	+0.064	−0.089	+1.414	+0.101	+0.554
24.....	+1.414	+0.157	−0.010	+0.276	−0.447	−0.339	−0.204
25.....	+0.707	+0.098	−0.006	−0.635	−0.008	+0.445	+0.436
26.....	+1.414	−0.479	+0.031	−1.304	+0.915	−1.126	+0.086
27.....	+1.000	−0.564	+0.036	−0.776	+0.785	−0.952	−0.387
28.....	+1.000	−0.891	+0.057	−0.431	+0.947	−0.644	−0.855
29.....	+1.414	−0.528	+0.034	+1.127	+0.987	+1.189	−0.113
30.....	+1.000	+0.117	−0.008	+0.793	−0.036	−0.659	−0.543
31.....	+1.000	+0.117	−0.008	+0.516	−0.222	−0.575	+0.802
32.....	+1.000	+0.112	−0.007	+0.293	−0.297	−0.353	−0.258
33.....	+1.000	+0.111	−0.007	+0.248	−0.307	−0.302	−0.613
34.....	+1.000	+0.111	−0.007	+0.065	−0.331	−0.081	−0.619
35.....	+1.414	+1.371	−0.091	−0.286	−0.461	+0.621	+0.721
36.....	+1.732	+0.247	−0.017	−1.492	−0.085	+1.152	+0.382
37.....	+1.000	−0.187	+0.013	−0.995	+0.531	−0.551	−0.511
38.....	+1.000	−0.340	+0.023	−0.922	+0.648	−0.797	−0.027
39.....	+1.414	−0.886	+0.060	+0.852	+1.194	+1.414	−0.151
40.....	+1.000	+0.121	−0.010	−0.967	+0.082	+0.500	+0.430

The factors for homogeneity in these equations are:

$$x=\delta V$$
$$y=[1.5075]\delta T$$
$$z=[5.0615]\delta\mu$$
$$u=\delta K$$
$$v=[1.3107]\delta\omega$$
$$w=[1.3418]\delta e$$

Log "unit error" $=0.2695$

The resulting normal equations are:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,d]$	$[a\,e]$	$[a\,f]$	$[a\,n]$
$+46,000x$	$-3.684y$	$-0.802z$	$+0.800u$	$+6.915v$	$-3.284w$	$-1.736=0$
	$+8.716$	$+0.543$	$+0.641$	-8.864	$+0.404$	$+2.585$
		$+1.026$	$+0.252$	-0.552	$+0.242$	$+0.870$
			$+18.623$	-1.688	-0.825	-0.623
				$+11.606$	$+0.476$	-2.545
					$+14.951$	$+0.903$
						$+9.721$

The solution of these equations gives for the corrections to the elements:

$\delta V = -0.003$ km	± 0.167 km
$\delta T = +0.0147$ days	± 0.021
$\delta\mu = +0.0000116$	± 0.0000081
$\delta K = -0.0932$	± 0.218
$\delta\omega = +0.0000455$ radians	± 0.0302 radians
$= +0^\circ.003$	$\pm 1^\circ.730$
$\delta e = +0.0033$	± 0.0112

FINAL ELEMENTS

$V = +6.20$ km	± 0.17 km
$T =$ J. D. 2416746.385	± 0.021 days
$K = 13.557$	± 0.218
$\omega = 265^\circ.353$	$\pm 1^\circ.730$
$e = 0.5033$	± 0.0112
$\mu = 39^\circ.05053$	± 0.00046
Period $= 9.218826$ days	± 0.000108
$a \sin i = 1{,}485{,}000$ km	
$[p\,v\,v] = 29.0$	

The sum of the squares of the weighted residuals has been reduced only from 33.6 to 29.0, showing that the preliminary elements were bettered very little by the least square solution. The probable error of a single position is ± 0.62 km. That for a single plate is slightly larger than ± 0.64 km. The value for $[p\,v\,v]$ given above is that derived from the forty positions used, seven of which were the mean of two plates, and one of three plates. The value of $[p\,v\,v]$ for the forty-eight plates taken independently is 33.4.

The solution is satisfactory, as may be seen from the following table. The residuals given by these elements are tabulated, and likewise a comparison of the differences produced by the changes

in the elements and those secured by direct substitution of the values of the unknowns in the equations of condition.

No.	O.−C.	Eph.−Equat.	No.	O.−C.	Eph.−Equat.
1.....	−0.11	−0.04	21.....	−0.75	−0.01
2.....	−0.69	−0.06	22.....	−1.15	0.00
3.....	−0.12	+0.04	23.....	+1.15	+0.02
4.....	−0.21	−0.05	24.....	−0.28	+0.02
5.....	+1.33	−0.01	25.....	+0.59	−0.03
6.....	+0.23	0.00	26.....	+0.24	−0.02
7.....	−0.41	0.00	27.....	−0.40	−0.07
8.....	−1.60	−0.01	28.....	−1.24	0.00
9.....	+0.30	0.00	29.....	0.00	+0.07
10.....	+0.25	0.00	30.....	−0.93	+0.01
11.....	−0.12	−0.02	31.....	+1.54	+0.01
12.....	+0.80	−0.01	32.....	−0.47	−0.01
13.....	−0.12	+0.01	33.....	−1.14	0.00
14.....	+1.56	+0.02	34.....	−1.18	−0.01
15.....	+1.28	0.00	35.....	+0.87	−0.06
16.....	+1.39	−0.01	36.....	+0.24	0.00
17.....	−0.21	0.00	37.....	−0.94	0.00
18.....	−0.88	+0.03	38.....	+0.04	0.00
19.....	−1.69	−0.01	39.....	+0.03	0.00
20.....	+0.47	+0.01	40.....	+0.62	0.00

In Fig. 3 I have plotted the velocity-curve of a_2 *Geminorum*, and the separate observations. The radius of the small circles represents the computed probable error of a plate, and the dotted line the velocity of the center of mass of the system.

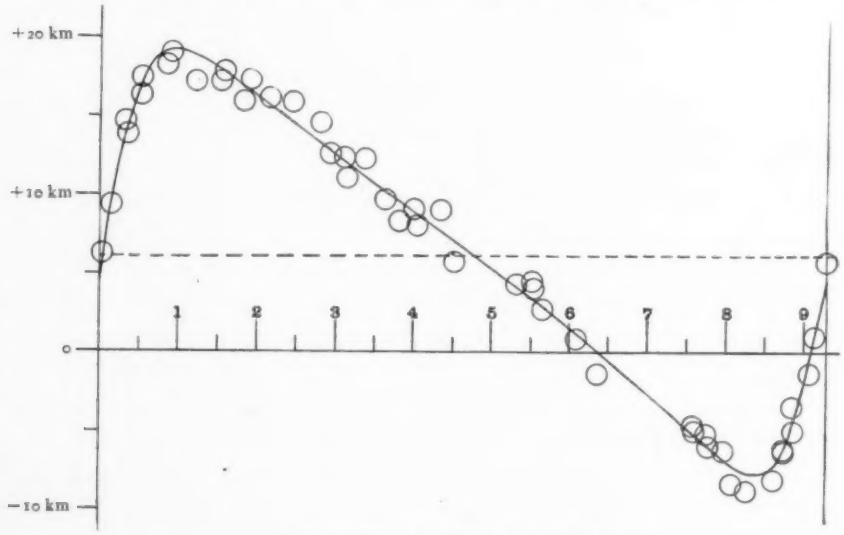


FIG. 3.—Velocity-Curve of a_2 *Geminorum*

THE VISUAL SYSTEM

The hope may naturally be entertained that a combination of spectrographic and visual results will eventually give a fairly accurate value of the parallax, masses, and the other physical constants of this unique quadruple system. Unfortunately the elements of the visual orbit are so indeterminate that no conclusion can be reached at present. Many orbits have been computed. An idea of their wide variation may be gathered from the following list of orbits given by Burnham in his *Catalogue of Double Stars*, advance proof-sheets of which were kindly sent me by the author. The date in the first column represents the last measures used in the respective determinations.

1831.....	Herschel	252.66 years	*Mem. R. A. S.*, **5**, 196, 1832
1841.....	Mädler	232.12	*A. N.*, **19**, 349, 1842
1845.....	Hind	632.27	*A. N.*, **23**, 377, 1846
1847.....	Mädler	519.77	*F. S.* **1**, 233.
1846.....	Jacob	653.1	*Mem. R. A. S.*, **16**, 321, 1847
1856.....	Thiele	996.85	*A. N.*, **52**, 39, 1860
1875.....	Wilson	982.9	*Handbook of Double Stars*
1877.....	Doberck	1001.21	*A. N.*, **91**, 119, 1878
1878.....	Thiele	720.	"*Castor*," Copenhagen, 1879
1889.....	Mann	265.7	*Sid. Mess.*, **9**, 385, 1890
1896.....	Burnham	Indeterminate	*Pop. Astr.*, **4**, 286, 1896
1898.....	Doberck	318.23	*A. N.*, **147**, 337, 1898
1904.....	Doberck	268.16 346.82 501.08	*A. N.*, **166**, 145, 1902

Burnham (reference above) considers that the problem of finding the elements is absolutely indeterminate at present, and likely to remain so for a century or so longer. Doberck (reference above) in his last paper gives three orbits of which he considers the one of period 347 years as the most probable, and there expresses the hope that the measures of the next twenty years may lead to a more accurate knowledge of the elements.

The relative velocity of the two components, as derived from the present discussion, is 7.14 km $\pm$ 0.23 km. Assuming Doberck's elements with period of 347 years, this would give a parallax of 0".05. On this assumption as pointed out by Miss Clerke,[1] the total mass of the system would be 12.7 times that of the Sun. These results must be considered as extremely uncertain.

[1] *The Observatory*, **28**, 209, 1905.

Attention may be called to one or two other points of interest in the system. Assuming for each spectroscopic system an inclination of 63°, the same as that given by Doberck for the visual system, the semi-major axes of the two systems are

α_1 *Geminorum*, $a = 1{,}435{,}000$ km
α_2 *Geminorum*, $a = 1{,}667{,}000$ km

These values are admittedly mere hypotheses, but they convey an idea of the size of the systems and emphasize the fact that they are probably of the same order of magnitude. The assumption that the inclination of the orbital plane of each of the two systems is roughly that of the main system is not unreasonable.

We have then, in *Castor*, two systems whose orbital dimensions are probably of the same order of magnitude. The brighter component has, however, the very great eccentricity of 1.50, while the fainter pair revolve in orbits which are practically circles (eccentricity = 0.01). This extraordinary difference seems, by the generally accepted theories of stellar evolution, to indicate that the brighter component is the older, and that the fainter is, spectroscopically speaking, a binary of relatively recent origin. α_2 has already approximated to the eccentricity of the main system of dimensions, enormously greater, while its own major axis is probably not much greater than that of its companion system, still almost circular. On the other hand, the mass of the fainter component should be about six times that of the brighter one.

The effect of tidal action on a system so eccentric as that of α_2 must be enormous where at periastron the stars are but one-third their apastron distance apart. Such an eccentricity, in fact, has generally been found only in those spectroscopic binaries which also show variability in their light. The question naturally arises whether any such phenomenon exists in α_2. A series of observations was accordingly made with the smaller of the two Bruce double-image photometers belonging to the Lick Observatory, attached to the twelve-inch equatorial.[1] Five or six independent settings were made in each of the four positions of the Nicol prism, and from forty to sixty separate settings constitute an observation.

[1] A description of this type of instrument is given in the *Annals of the Harvard College Observatory*, 11, I, 105, 1879.

In each case the brightness of a_2 was compared with that of a_1, a method of procedure for which the double-image polarizing photometer is particularly adapted. In the reductions the magnitude of a_1 was assumed to be 3.70. Below are given the results of these observations; and I have prefixed for the sake of completeness, the Harvard observations of the same pair (*loc. cit.*).

PHOTOMETRIC OBSERVATIONS OF α_2 *GEMINORUM*

Date G. M. T.	Julian Day	Magn. a_2	R	Notes
HARVARD OBSERVATIONS—				
1878, February 15^d 13^{h}8....	2407031.565	2.79	+0.09	
13.9....	.577	2.66	+0.22	
16 11.6....	32.483	3.18	−0.30	
11.7....	.487	3.32	−0.44	
11.8....	.492	3.11	−0.23	
11.8....	.493	3.04	−0.16	
11.9....	.496	2.61	+0.27	
11.9....	.496	2.71	+0.17	
18 10.6....	34.441	2.66	+0.22	
10.6....	.441	2.72	+0.16	
	Mean	2.88		
LICK OBSERVATIONS—				
1905, January 16^d 21^h 5^m	2416862.879	2.73	+0.01	
26 18 22	72.765	2.72	+0.02	
27 14 17	73.595	2.79	−0.05	
27 22 26	73.935	2.58	+0.16	
28 14 29	74.604	2.75	−0.01	Seeing poor
February 7 15 8	84.626	2.66	+0.08	" "
8 14 49	85.617	2.71	+0.03	
12 14 35	89.608	2.52	+0.22	" "
12 22 6	89.921	2.84	−0.10	
13 14 57	90.623	2.71	+0.03	
23 14 53	6900.619	2.80	−0.06	
27 14 56	4.622	2.95	−0.21	
28 14 38	5.610	2.84	−0.10	
March 1 14 48	6.607	2.71	+0.03	
6 14 46	11.615	2.73	+0.01	
8 14 59	13.624	.88	−0.14	
	Mean	2.74		

No marked variation of regular period can be deduced from these observations. Such a variation, if it exists at all, is evidently small.

No irregularities have been detected in the velocity-curve of the spectrographic orbit.

PACIFIC MAIL STEAMER "SAN JUAN,"
Panama, January 24, 1906.

ON REFLECTING TELESCOPES OF RELATIVELY SHORT FOCUS[1]

By H. C. VOGEL

Just as, since the earliest days, there has existed a sort of competition between the refractor and the reflector, and a new success in one field has been soon equaled in the other, so also in recent times, after what is probably the acme of perfection in the production of great refractors had been attained a decade ago, the improvement of reflecting telescopes was undertaken, with great success, and today refractors and reflectors rank as of equal value. It is unlikely that very important improvements are to be expected in either of these so different instruments, and therefore we are rather compelled to assign to each of them a field of work for which it is particularly adapted. Thus it is likely that refractors of long focus will receive the preference when the largest usable field of view is in question. Refractors having objectives composed of more than two lenses, which, in consequence of the relatively short focus which can be given them, are particularly adapted for photographing large regions of the heavens and extensive masses of nebulæ, will find continued use in the execution of surveys like the *Durchmusterung*, and for finding comets and small planets. *Per contra*, reflecting telescopes have at present attained an immense advantage for the observation of nebulæ and star clusters of small extent, and they will doubtless permanently retain this advantage, inasmuch as it is based upon the characteristic properties of the mirror.

The well-known Ring Nebula of *Lyra* may serve here as an example. In a large refractor it appears as an elliptical ring, and one is easily struck by the unequal distribution of the brightness and unequal sharpness of the boundary, particularly at the ends of the major axis of the ellipse. An observer with a particularly good eye also gets the occasional impression of some brighter stellar points in the ring, and possibly of a small star at the center of the

[1] Paper presented to the *Kgl. Akademie der Wissenschaften*, Berlin, March 15, 1906. *Sitzungsberichte*, 1906, No. 14.

nebula, but he cannot retain these details in his vision with certainty. A photograph taken with one or two hours' exposure with a refractor having an objective corrected for the chemically active rays gives a better result. A fairly bright central star can be recognized in the interior of the nebula, and has a faint and somewhat diffuse companion.

The shadings in the ring of the nebula are very clearly perceptible. But on a photograph taken with one of the recent reflectors an exposure of only ten minutes yields an overexposed image of the ring.

The *Orion* nebula may be cited as a further example. The delicate details in the outlying portions of this nebula, which can just barely be seen by direct observation with a large telescope, but which cannot be perceived with enough certainty to permit a drawing to be made, can indeed be photographed with the refractor; but only with an exposure time in which a reflector of comparable size with the refractor would depict the nebula as a closed and almost circular mass.

This condition of affairs is particularly occasioned by the fact that in the focal image of the mirror all the colors are perfectly united, while the achromatism of a telescope with an objective of two lenses always leaves much to be desired; and since the diameters of the circles of chromatic aberration increase with the focal length of the refractor, the errors due to the imperfect achromatism soon exceed all the other errors of the objective. This defect of the refractor is especially conspicuous for nebulæ yielding the typical nebular spectrum, like the two which I have just cited as examples. I would here point out especially that it may happen that the pictures taken with a reflector appear differently from those with a refractor, if the ultra-violet rays of the light from a nebula having a discontinuous spectrum are more or less lost by absorption in the glass of the objective. This is particularly conspicuous if the distribution of intensity of the spectral lines is different in the different parts of one and the same object, as was proven to be the case for the *Orion* nebula by Mitchell at the Yerkes Observatory and by Hartmann at the Potsdam Observatory. In some parts of the nebula the principal nebular line in the green is exceedingly weak, while the ultra-violet line at λ 3727 is relatively strong throughout the whole

nebula, whence may be explained the differences which may be so readily noticed between photographs taken with a refractor and a reflector. It is to be further noted, and to be regarded as a disadvantage to refractors of long focus, that the difficulties are met with as a result of a defective achromatism in direct observations of gaseous nebulæ and neighboring stars. The maximum intensity in the continuous spectrum of a star lies between λ 560 and λ 570 $\mu\mu$, while in the nebular spectrum the brightest lines have wave-lengths λ 501, λ 496, and λ 486 $\mu\mu$. In a telescope with a focal length up to about 4 meters, the differences of the points where these wave-lengths unite can hardly amount to 1 mm, measured along the optical axis, but with greater focal length they increase to several millimeters, and the eye is then not able to so accommodate itself that the stars and nebula will appear simultaneously sharp.

The astonishing advances which have recently been made with the aid of reflecting telescopes in our knowledge of the nebulæ depend in the first instance on the application of photography. We may say that it has opened a new era for this so interesting branch ot science. Objects which formerly were visible only with the mosf powerful instruments are readily photographed with small reflectors and the pictures give a richness of detail which could hardly be suspected in direct observations.

Further success is attained by the efforts to make the surface of the mirrors more perfect, and to give them the form of a paraboloid of revolution instead of a sphere. In this way the rays are united as perfectly as possible, at least in the optical axis, and in its neighborhood a better union of the rays is effected than with a spherical surface, from which an image free from error cannot be obtained even in the axis itself, on account of the spherical aberration. We are also thus put in the position for the first time of increasing the ratio of aperture to focal length, and thus of enormously increasing the intensity of the images both of extended celestial objects and of point-like stars (in the case of the latter particularly by diminishing the effect of the unsteadiness of the air). While the old reflectors of Herschel, Lord Rosse, Lassell, Draper, and others did not exceed the angular aperture of 1:9, we meet with the following values of this ratio in recent instruments:

		Aperture	Focal Length
1:6	Paris	119 cm	7.1 m
1:5.8	Lick Observatory (Crossley Reflector)	91	5.3
1:5.4	Common	152	8.2
1:4.9	Roberts	51	2.5
1:4	Yerkes Observatory	60	2.4
1:3.7	Schaeberle	30	1.1
1:3	Meudon	100	3.0
1:2.2	Common	52	1.1
1:1.54	Schaeberle	33	0.51

With the increase of perfection in the construction of mirrors, attention has also been given to the errors which are attached to them fundamentally, and these have been exhaustively investigated. I cite here the most important papers referring to the subject in so far as they are known to me,[1] and I would especially call attention to two very interesting papers by Schwarzschild, which appeared last year under the title "Untersuchungen zur geometrischen Optik."[2] The conditions for reflecting telescopes are explained in a very clear, and, by the use of the notion of Bruns' "Eikonal," in a highly elegant, manner. Schwarzschild's investigations in the second part of his paper have indeed led to the view that it may be possible by the use of two mirrors to produce an image perfect over a diameter of field of several degrees. The practical execution of his

[1] *Monthly Notices of the R. A. S.:* **47**, 244, 1887: J. F. Tennant, "Notes on Reflecting Telescopes." **47**, 394, 1887: McLaren, "On the Images Formed by Reflecting Mirrors, and Their Aberration." **62**, 345, 1897: H. C. Plummer, "On the Images Formed by a Parabolic Mirror."

Astronomical Journal: **16**, 25, 1896: J. M. Schaeberle, "Derivation of Fundamental Formulas for the Cassegrain (and Gregory) Telescopes." **18**, 35, 1897: J. M. Schaeberle, "On a Fundamental Optical Defect in the Images Formed by a Parabolic Reflector." **18**, 89, 1897: C. L. Poor, "The Aberration of Parabolic Mirrors." **19**, 17, 1898: J. M. Schaeberle, "General Theory of the Aberration in the Focal Plane of a Parabolic Mirror."

Astrophysical Journal: **7**, 114, 1898: C. L. Poor, "The Aberration of Parabolic Mirrors." **7**, 362, 1898: C. W. Crockett, "The Parabolic Mirror." **12**, 219, 1900: S. C. Reese, "Field of the Reflecting Telescope."

Popular Astronomy: **5**, 518, 1898: F. L. O. Wadsworth, "A Note on a New Form of Mirror for a Reflecting Telescope." **6**, 33, 1898: J. M. Schaeberle, "On the Definition and Intensity of a Star's Image in the Field of View of a Parabolic Reflecting Telescope." **6**, 39, 1898: J. M. Schaeberle, "On the Aberration of Parabolic Mirrors."

[2] *Astron. Mitteilungen der Königl. Sternwarte zu Göttingen*, Teile 9 und 10.

suggestions would, according to my experience, doubtless meet with some very grave mechanical and technical difficulties. The triumph of obtaining a fairly large aplanatic image in a telescope of large angular aperture (to which these investigations particularly apply), having the other good qualities of reflector images, would be, however, of such conspicuous significance that it would be worth the expenditure of a great deal of pains. It is true that a quarter of the whole light would be lost by the obscuration of the principal mirror by the second mirror, to which in the example given in the paper a diameter of half that of the large mirror was assigned. The difficulties which I fear in the execution of the plan do not lie in the production of the mirror, but essentially in the rigid connection of the two mirrors, and in their fine adjustment with respect to each other and to the photographic plate, which is troublesome even in the simplest form of reflecting instrument—a mirror with a photographic plate at the focus. This troublesome adjustment would have to be made often, inasmuch as glass mirrors with a silvered surface are at present in general use, and the silver surface has to be renewed at short intervals.

At present we must content ourselves with the use of mirrors having large angular aperture, with all the errors that attach to them. As already indicated, these consist in the fact that in a perfectly parabolic mirror an accurately round image of a star is obtained only in the optical axis, while outside of the axis we can only obtain images of a star which are affected by a coma. The image formed in a plane at right angles to the optical axis of the mirror (as on a photographic plate) assumes the shape of a pear, which becomes the more distinct the farther the star is situated from the axis. The distribution of light in these images is unequal, with the greatest intensity at the point. It is not possible to obtain a round image of a star situated away from the center by any alteration of the focus of the plate. It is thus not possible to make a sort of compromise in respect to the focus, as can be done with the compound objective, in order to get the smallest amount of poor definiton extending uniformly over a larger area.

The image curvature, which also occurs as an error in mirrors, produces a further deformation of the images which are not situ-

ated in the axis, but this does not equal the effect of the coma until the distance from the axis is large.

The following table, which I have taken from Schwarzchild's paper (Part 2, p. 11), shows how large these errors become for different ratios of aperture and for different extents of the field of view.

Ratio of Aperture	Diameter of Field of View	Spreading from Image Curvature	Spreading from Coma
1:10	$\frac{1}{2}^\circ$	0″.4	1″.7
	1	1.6	3.4
	2	6.3	6.8
	4	25.2	13.6
1:3	$\frac{1}{2}$	1.3	18.7
	1	5.0	37.4
	2	20.0	74.9
	4	83.8	149.8

This summary indicates that the usable field of view of telescopes with an angular aperture of 1:3 will have a diameter of from 30′ to 40′ only. But when we reflect that the dimensions of a very great number of nebulæ do not exceed 20′, we conclude that a rich field of work is assured for a mirror of the above-named ratio. It is here to be assumed that the perfection of the mirror will be such that it will be possible to obtain the images small in respect to the aperture (which would again furnish the advantage of great light-power), so that they would be comparable in richness of detail with the plates taken with reflectors of greater focal length. I would further call attention to the fact that matters may be helped for an object of larger extent by photographing different parts of it separately, and that, when the brightness of the object is sufficient, a usable image of greater extent can always be obtained by reducing the aperture of the mirror. The size of the usable field of view, moreover, increases with great rapidity with the decrease of the angular aperture.

A reflecting telescope of large angular aperture offers decided advantages for spectrographic observations of nebulæ and faint stars, as may be easily seen. The intensity of the unit of surface increases in proportion to the square of the diminution of the extent of the images of nebulæ. Moreover, since the star disks produced

on the photographic plate by the unsteadiness of the air are smaller for a short focus than for a long focus, all the faint stars will be obtained on the plates for instruments of short focus, which, for an instrument of longer focus, could not affect the bromide of silver on account of the too feeble intensity of the star disks caused by the unsteadiness, which are also enlarged as a consequence of the longer focus. These considerations led Professor Scheiner a few years ago to begin experiments in this direction at the Astrophysical Observatory with a provisionally constructed instrument (a mirror of 32 cm diameter and of 96 cm focus). But as the mirror was spherical, and the star disks as a consequence necessarily had considerable dimensions even in the optical axis itself, the results in no wise corresponded to the expectations.

The highly interesting discovery a few years ago of a nebula about the fading *Nova Persei*, which was of much importance for the solution of the problem of the nature of temporary stars, spurred me on to have renewed experiments made with mirrors of short focus at this observatory, in order that thus in general the program of the observatory might be developed in this direction, and in particular that important observations of that sort for which a reflecting telescope appeared particularly suited, could be made here, having previously necessarily been left for observers abroad.[1] In the year 1904 I received from Steinheil, of Munich, a mirror of 30 cm diameter, of which, however, only a diameter of 24 cm had been figured by the optician. The focal length was 90 cm, and accordingly the ratio was 1:3.8. Dr. Eberhard made an investigation of the mirror by Hartmann's method of extra-focal plates, with the result following (p. 377).

Upon the conclusion of this investigation I had a solid mounting given to the mirror, particular weight being laid upon the stability and possibility of a fine adjustment of the plate with respect to the optical axis of the mirror. The mounting was constructed by O. Toepfer & Son, in Potsdam, according to the precise specifications

[1] Hitherto no reflecting telescope of short focus has been in use in Germany. The fact that Wolf, of Heidelberg, gave the name of the Bruce Telescope to the instrument given by Miss Bruce, with which he makes his beautiful plates of stars and nebulæ, has repeatedly led to the misunderstanding that this was a reflecting telescope.

of myself and Dr. Eberhard. After Dr. Eberhard, in conjunction with Dr. Ludendorff, had in a most careful manner effected the somewhat troublesome adjustment of the telescope, which was used in connection with the oft-mentioned refractor of 32.5 cm aperture, excellent plates were obtained by those gentlemen of the

Radius of Zone	Deviation Measured in the Axis
54 mm	+0.28 mm
69	+0.13
84	+0.09
100	−0.14
114	−0.40

best-known objects (nebula in *Orion*, Spiral nebula in *Canes Venatici*, the Dumbbell nebula, etc.) in the winter of 1904–5, and these furnished a proof that very useful results could be obtained even with an instrument of such small dimensions.

Meanwhile I received from Mr. B. Schmidt, of Mittweida (Saxony), of whose special accomplishments in the production of paraboloic surfaces I had heard, a mirror of 40 cm diameter and 2 meters focus, for examination and trial. The investigation of this mirror by Dr. Eberhard disclosed so great perfection in the union of the rays coming from different zones of the mirror that I inquired of Mr. Schmidt whether he would be willing to undertake the very laborious work of producing a mirror having a ratio of aperture to focal length of about 1:2.5. After his assent, we agreed together that the mirror should have a usable aperture of 40 cm and a focal length of 93 cm, and that the deviations in the union of the rays at the focus should not exceed $\pm$ 0.1 mm, measured along the optical axis. It will appear from what follows how Mr. Schmidt fulfilled these conditions, and I would further remark that the time of delivery of only three months after the definitive order was strictly complied with.

I have for the time been obliged to abandon my original desire of giving this mirror a mounting of its own, inasmuch as its equipment in an adequate manner would have involved large expense and, still worse, a long time, so that my wish to test the telescope as soon as possible by celestial observations would have had to be

postponed for at least a year, as with the new mounting a suitable place for observing would also need to be provided. Accordingly, I had this telescope mounted by Messrs. Toepfer & Son in a similar manner to the mirror of 30 cm diameter already mentioned, and attached the reflecting telescope rigidly to the tube of the small photographic refractor. To avoid overloading this instrument, the optical portion and the eyepiece attachment of the photographic tube were removed. The visual guiding telescope of the refractor of 23 cm aperture has served as guiding telescope for the plates taken with the mirror. The weight was further relieved by the use of nickel-aluminum for the cell of the mirror and for the supports of the plate-holder. The mirror has a thickness of 58 mm and a diameter of 44 cm with a usable surface of 41 cm, and the focal length is 92.7 cm. The tube, made of thin sheet steel, has a diameter of 47.8 cm, and to one of its ends the mirror is attached to a very solid cell resting on a ring of 30 cm diameter; at the other end the steel tube is strengthened by a ring having an opening of 45.8 cm. To this are attached three bars of 8 mm thickness which support the circular section of 90 mm diameter which carries the plate-holder. The arrangement for the precise focusing of the plate, as well as for inclining it to the optical axis and for giving the plate a slight lateral displacement, has been adopted from the mounting of the 30-cm reflector, on which it has proved very satisfactory. The size of the plate is 5×5 cm. The scale with vernier which can be read by a microscope makes it possible to set the plate at the focus with an accuracy of 0.05 mm. A setting incorrect by only 0.1 mm is enough to appreciably impair the image. Up to the present an effect of the temperature on the focal setting has not been demonstrable between the temperatures $+5°$ and $-6°.5$ C. Since Drs. Eberhard and Ludendorff completed a careful adjustment of the telescope, at the end of October 1905, photographs of celestial objects have been made by them on every favorable occasion, although the number of plates is unfortunately not very large on account of the exceptionally bad weather during this past winter. Nevertheless, I believe I am justified in declaring that I regard our instrument as one of the most perfect of its kind in existence at present.

After these general considerations I now take up the details of the Schmidt reflector having the ratio of aperture to focal length of 1:2.26.

1. *The investigations of the zones* of the mirror from measurements by Dr. Eberhard (E.) and B. Schmidt (Sch.) gave the following deviations measured in the optical axis, for the points of union of the rays.

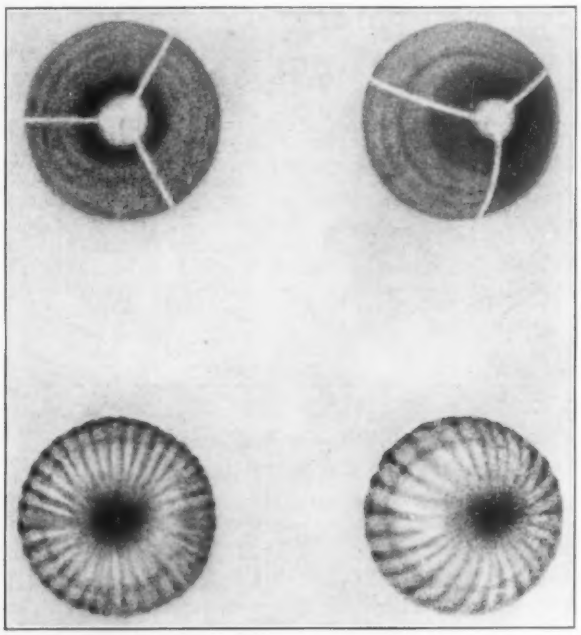
Radius of zone	Deviation		Radius of Zone	Deviation	
	E.	Sch.		E.	Sch.
40 mm	— mm	0.00 mm	147 mm	+0.01 mm	— mm
65	—	.00	150	—	−0.02
70	+0.01	—	160	—	— .03
80	+ .03	—	165	— .03	—
90	—	+ .02	170	—	— .03
100	+ .03	—	180	—	— .04
110	—	+ .03	185	— .10	—
115	+ .07	—	190	—	— .04
125	—	+ .01	195	— .09	—
135	.00	—	200	—	— .01
140	—	— .005	205	—	+ .01

The values by Eberhard are somewhat larger than those of Schmidt, but the latter are the more trustworthy, since Eberhard's measures lie at the limit of what can be accomplished by the method of extra-focal images, while Schmidt could go farther with the observations of the interfering images in the focus. In both determinations the position and width of the zones was different, as may be seen from the summary, and this may not have been without effect on the result. The course of a curve drawn through the points of union determined by observation is very clearly seen in both series. If the center of the disk of the image is desired, the deviations measured in the axis are to be multiplied by the angular aperture of the zones under consideration. With the full aperture of the mirror values are derived for the maximum which are in good agreement with those obtained from direct measures of star-images.

2. I have measured on different plates and on very many stars, and have found *the size of the smallest images* in the neighborhood of the axis to be 0.015 mm, corresponding to 3″.3; these points are not perfectly regular in shape, and are somewhat dull. The

diameter of the round and uniformly blackened star-images came out to be 0.03 mm or 7″.3.[1]

3. *Extra-focal images* taken with the full aperture of the mirror are seen under the microscope to be of great uniformity and allow us to infer from this uniformity of the distribution of light that the zonal errors are exceedingly small. It is further interesting to see



FIGS. 1–4

in them a shadow of the plate-support with its three bars. I regard this as an excellent criterion for the extraordinarily good quality of the mirror, for such an image can be formed only when the separate zones belong to one and the same paraboloid of rotation. If the axes of the separate zones do not precisely coincide, or if the parabola which corresponds to the sectional surface of the paraboloid in the axis does not run uniformly, but forms small waves,

[1] With a focal length of 92.7 cm the relation between the linear extent at the focus and the angular value is:

1 mm = 3′.71 = 222″.5; 1′ = 0.27 mm.

the foci of the separate zones may indeed fall at the same distance from the vertex of the paraboloid (as indicated by the zonal test) without actually coinciding. They then lie in a surface beside each other, and in such a case the stars may appear drawn out at the focus (astigmatic error) or even round, but of greater extent and with more irregular boundaries than in a more perfect mirror. I believe that the accompanying figures, which I have made from extra-focal star plates, will be of interest for the possessors of reflecting telescopes. Fig. 1 is the extra-focal image of a star in the axis; Fig. 2, that of a star at some distance from the axis, both of these referring to the Schmidt mirror. Figs. 3 and 4 are extra-focal plates of stars in a less perfect mirror, in one case in the axis, and in the other at a slight distance therefrom.

4. *Coma.*—I thought it of interest to make some more accurate measurements on the images which are formed on the plate at the focus at different distances from the axis of the mirror when its full aperture was used, hence when the angular aperture is 1:2.26. For this purpose a plate was prepared on which δ *Orionis* was successively photographed in the axis and at equal distances of 10′ therefrom, with the uniform exposure time of one minute. On account of the richness of this region in the heavens, a large number of fainter stars are contained on the plate, so that numerous measurements could be made on these, the results of which I communicate here.

Distance from the Axis	Length of the Coma	
0′	0.000 mm	0′.0
10	0.040	8.9
20	0.113	25.1
30	0.188	41.8
40	0.278	61.9
50	0.375	83.4
60	0.483	107.5
70	0.595	132.4

The measures were made on seven pictures of δ *Orionis* up to a distance of 60′ from the axis, as well as on twenty-three images of fainter stars to a distance of 67′. The results of these can be very well represented by a curve from which the value for the linear

extent of the star-image may be taken for distances of 10′, 20′, etc., from the axis, and are given in the table above.

I have also determined, from measurements on several stars on two plates, the size of the coma at a distance of 56′ from the axis, with the mirror diaphragmed down to 24 cm, corresponding to an angular aperture of 1:3.86. I found the linear extent of the images to be 0.135 mm or 30″. A comparison of these measures with the data from Schwarzchild's table, already cited, indicates that the spreading turns out smaller than was to be expected from the computation.

I have further determined from numerous star-images the ratio between linear extent and greatest width. It is very accurately 3:2. The angles formed at the vertex of the star-images affected by coma came out to be exactly 60°, and the distance of the perpendiculars on the axis of length of the figure, which corresponds to the greatest width, I found to be two-thirds of the axis of length from the vertex. If circles are drawn in an angle of 60° in such a way that their circumferences touch the sides of the angle (Fig. 5), the precise figure of the distortion images of the stars outside the axis will be obtained. I have sought to represent the distribution of light on them in Fig. 6. With a sufficient intensity of light the whole figure will become so black on the negative that no shading can be perceived. A slight narrowing before the point is reached is more noticeable than in the image of fainter stars, which probably has its cause in the irradiation of the most intense place in the photographic film at the vertex of the figure. In the case of very faint stars the figure is not closed, and one can only recognize an angle, the sides of which appear without any boundary inward but bounded by perfectly straight lines outward. The arc indicated in Fig. 6 often appears, and not seldom are the star-images provided with a narrow lengthwise streak—the shadow of one of the bars which support the plate-holder, if the linear extent of the image accidentally coincides with the direction of one of the bars.

5. *Performance of the Schmidt mirror in comparison with other instruments.*—Only a small amount of data is available as to the performance of reflectors with very large angular apertures. Photographs of several of the better-known nebulæ were made by M.

Rabourdin with the reflector of the Observatory at Meudon, 1 m: 3 m, and M. Janssen has reported on these in *Comptes Rendus*, **126** and **128**. From the descriptions, which do not go farther into detail, the conclusion cannot be drawn that the instrument possesses remarkable properties, and must be regarded as an improvement as compared with other instruments. *Per contra*, the few pictures in *Comptes Rendus*, **128**, which, it is true, were not well reproduced, only testify that either the focusing of the plate was insufficiently accurate, or that the mirror is not free from errors. In particular, the stars do not appear as disks in the pictures of

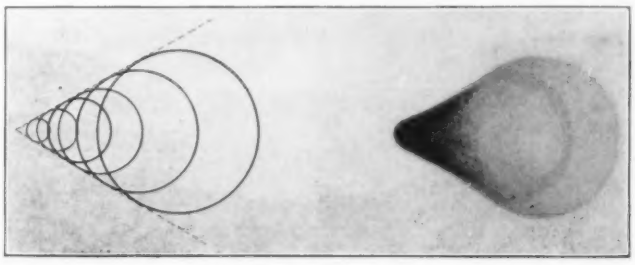


FIG. 5

FIG. 6

the cluster in *Hercules* which were taken with different exposures, but as irregular elliptical rings with or without a stellar nucleus.

Schaeberle's highly interesting attempt to produce a mirror with an angular aperture of 1:1.54 seems to have been a success,[1] but, from the small number of plates hitherto described, its advantages cannot, in my opinion, be regarded as sufficiently well established. The paper cited is accompanied by a photographic reproduction of the Ring nebula in *Lyra*, which, however, shows nothing striking. The too great enlargement (75 times) of the photograph, as sent by the author for publication, was unfortunately doubled by the editor, so that, in consequence of the very pronounced silver-grain, almost every detail is lost, as well as any chance to get an idea as to the quality of the definition of the mirror. Schaeberle in two other papers has communicated observations on the Ring

[1] *Astronomical Journal*, No. 539, **23**, 109–113, 1903: "On the Photographic Efficiency of a 13-Inch Reflector of 20 Inches Focus."

nebula and on the Dumbbell nebula.[1] Here, too, the images were greatly enlarged, 22 and 15 times respectively. From these photographs I have not been able to convince myself of the presence of a spiral structure which was said to appear with long exposure in the exterior parts of this nebula, as well as in the nebulæ in the neighborhood of *γ Cassiopeiae* and in the grouping of the stars in the cluster of *Hercules*.

In consequence of the unfavorable weather in the past autumn, it was unfortunately not possible to obtain here photographs of the Ring nebula in *Lyra* and of the Dumbbell nebula. The nebulæ of *γ Cassiopeiae* appear on our plates in complete agreement with those on the photographs of Roberts.

Schaeberle's remarks as to the astonishing light-power of his instrument is respect to depicting faint stars is, however, confirmed by the observations made here, as I shall show farther on. Since nothing further is known to me as to mirrors with relatively very short focal length, it only remains to compare the results thus far obtained at Potsdam with those secured by Roberts[2] with a mirror of 51 cm diameter and a ratio of 1:5, at his private observatory, and with those obtained at the Lick Observatory by Keeler with the Crossley reflector of 91 cm diameter and a ratio of 1:6.

The Schmidt 41-cm mirror with full aperture shows with 2 minutes' exposure the brightest portion of the nebulæ in the *Pleiades*. With an exposure of 30 minutes all the details appear which were obtained on Keeler's plates with the Crossley reflector in 4 hours, and something more than the 4 hour exposure of Roberts[3] yielded. The usable field of view with the 41-cm reflector at full aperture is too small to represent the *Pleiades* on one plate, as is possible with telescopes of less angular aperture.

The nebulæ about *γ Cassipeiae* appear as distinctly in 40 minutes with full aperture as on the plates taken by Roberts in 90 minutes on October 25, 1895 (Vol. **2**, p. 159, Plate 25, of Roberts.)

[1] *Astronomical Journal*, No. 547, **23**, 181–182, 1903. "The Ring Nebula in *Lyra*, and the Dumbbell Nebula in *Vulpecula*, as Great Spirals." No. 552 (**23**, 225, 1903), "On the Spiral Character of the Nebulosities Surrounding *γ Cassiopeiae*."

[2] *Selections of Photographs of Stars, Star Clusters and Nebulae*, Vol. II, p. 159, Plate 25.

[3] *Loc. cit.*, Vol. I, p. 47, Plate 11.

Hind's variable nebula near *T Tauri*, which Keeler[1] obtained with the Crossley reflector by an exposure of 4 hours, can be distinctly seen on a plate taken in 2 hours with the Schmidt reflector.

An exposure of 2 hours on the Crab nebula (*N. G. C.* 1952, *h* 357) surpasses that obtained by Roberts[2] in 3 hours. The photographs do not resemble the fantastic picture of the nebula drawn by Lord Rosse from the appearance in the great reflector (of 183 cm aperture), from which the nebula received its name. The brighter part of the nebula has the form of a rhomb. Its exterior boundary is indeed irregular and shows at one place a very marked indentation, but the outlying portions cannot be detected in the manner of the above-mentioned drawing. The numerous stars in the neighborhood of the nebula shown by Roberts' plate can all be found on our photograph, on which a few more are present; the extent of the nebula is also somewhat greater than on Roberts' plate. The very interesting nebulæ near *ζ Orionis* (*N. G. C.* 2023 and 2024) are visible on a plate exposed only 10 minutes, as is even the faint streak of nebula which is at one place very sharply bounded by a straight line and has a circular sharply defined indentation. I have at hand only a beautiful picture of this nebula by Herr von Gothard, which was obtained with a reflecting telescope of small angular aperture in about 8 hours. The accompanying sketch (Fig. 7) was made by Dr. Münch from a 2 hours' exposure with the Schmidt mirror when diaphragmed down to 31 cm. The faintest stars are included only in the neighborhood of the nebulous matter.[3]

The aperture of the 41-cm mirror was cut down to 24 cm in order to obtain a larger field of view of different objects of large extent, thus giving an angular aperture of 1:3.86. After subtracting the area of the mirror shaded by the apparatus for supporting the plate, the diameter of the surface of the mirror actually used amounts to only 21.7 cm. All the details in the nebula of *Orion* exhibited by a plate of Roberts[4] with 3 hours and 25 minutes exposure, can

[1] *Monthly Notices*, **60**, 424, 1900. [2] *Loc. cit.*, Vol. I, p. 53, Plate 14.

[3] The drawing and still better the original agrees well with the photograph by Roberts (*Astropyhsical Journal*, **17**, Plate IV), to which my attention was called during the printing of this paper. Roberts did not give any data as to the duration of exposure.

[4] *Loc. cit.*, Vol. I, p. 59, Plate 17.

be recognized on our exposure of 1 hour, and all the stars on Roberts' plate were also obtained. The central brighter parts of the nebula which were somewhat overexposed in 1 hour could be admirably

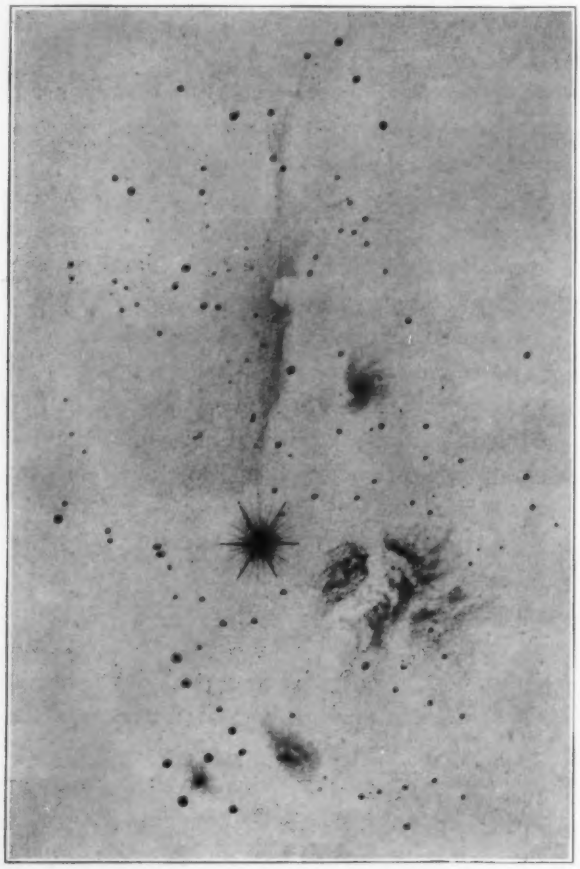


FIG. 7.—Nebulae near *ζ Orionis*

represented on more fine-grained and less sensitive plates with exposures of 10 and 30 minutes.

A very beautiful picture was obtained of the interesting spiral nebula *M* 33 *Trianguli* (*N. G. C.* 598, *h* 131) in a 2 hours' exposure, with an angular aperture of 1 : 3.86, but in consequence of its very small linear extent it does not fully equal in respect to the finest details

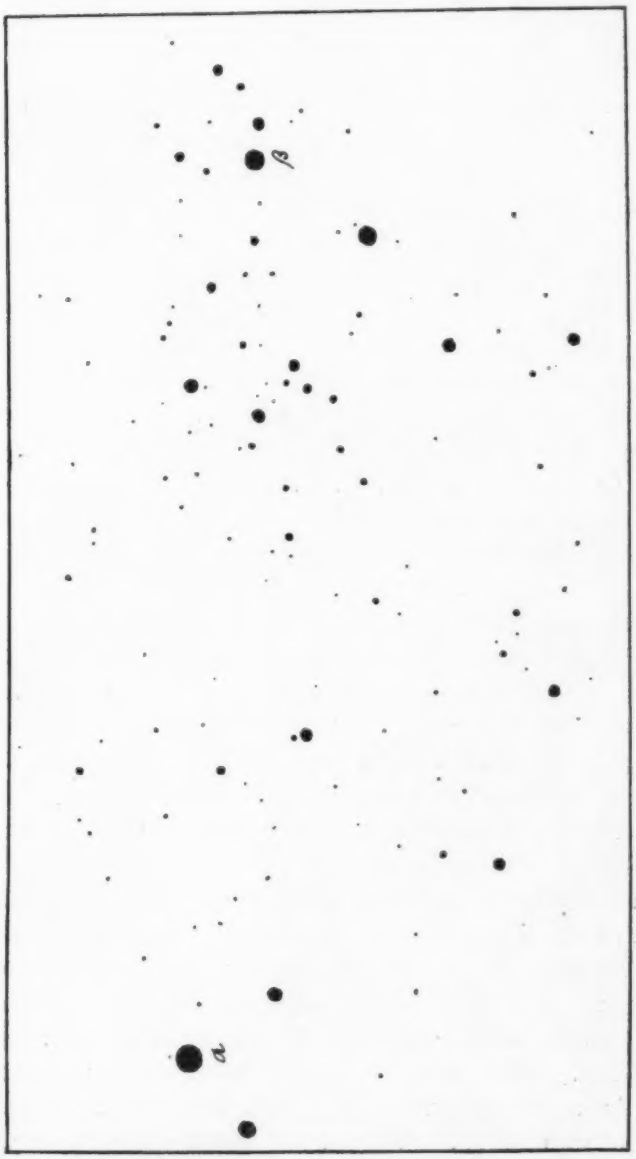


FIG. 8.—Region of numerous stars, 4m following ε *Orionis*
α, 6.8 mag., *B.D.*, −1°.1004. 1900.0: $5^h\ 35^m\ 46^s$; −1° 10′ 53″.
β, 8.4 mag., *B.D.*, −1°. 990. 1900.0: 5 33 51 ; −1 13 37 .

the plate obtained with the Crossley reflector with $3\frac{1}{2}$ hours' exposure, although it approaches it very closely. The Potsdam plate is not inferior to the photograph by Roberts with $2\frac{1}{4}$ hours' exposure (Plate 10, p. 65, Vol. 2).

On a plate of the cluster in *Hercules*, taken with the aperture cut down to 24 cm, as many stars were obtained in 5 minutes as on a plate of from 60 to 120 minutes taken with the 32.5-cm objective of the Potsdam photographic refractor.

A photograph of the extraordinarily rich region around *γ Cassiopeiae* shows, with 60 minutes' exposure, many more stars than appear on the reproduction given by Roberts (Plate 4, p. 33, Vol. 1) of his plate taken in 90 minutes on January 17, 1890. The nebulæ in the neighborhood of the star can be very distinctly seen, which were not visible on those plates of Roberts.

The following remarks may be added as to the light-power for depicting faint stars. Mr. R. H. Tucker[1] prepared at the Lick observatory small charts of different parts of the heavens, on which all stars which were even barely visible with a great refractor of 91.5 cm aperture under good atmospheric conditions are included. We have thus far been able to test only one of these charts (No. 3, of the region near *ε Orionis*), and we have obtained the satisfactory result that with an exposure of only 10 minutes at the full aperture of the Schmidt mirror, not only were all the faintest stars of magnitude 16 to 17 obtained which are visible in the powerful Lick telescope, but the number of the faint stars is decidedly larger, although at the time the silvering of the mirror, which often has to be renewed, had already suffered considerably.

On the basis of a measurement of the plates made by Drs. Eberhard and Ludendorff, Dr. Münch has prepared a chart in which all stars are entered which should be distinctly recognized as such. On this some inaccuracies in Tucker's drawing could be corrected, and I believe that the reproduction of this chart (Fig. 8) may be of interest. The chart extends in declination somewhat farther than Tucker's drawing, but in right ascension includes only about half as much as his. In equal regions of Tucker's drawing and of the photograph obtained here, he has forty-four stars fainter

[1] *Publications of the Astronomical Society of the Pacific*, **8**, 95, 1896.

than the twelfth magnitude, while the photograph shows 61 stars below this magnitude.

I hope that further interesting results may be brought to light with this beautiful mirror, particularly if we are successful in attaching a suitable spectrograph to the reflector. The prospect of this is indeed still somewhat remote, as the reflector must first receive a mounting of its own, so that a longer series of observations can be carried out without interruption, which is not possible in the present provisional attachment of the instrument to the photographic refractor. Furthermore, this admirable refractor can only be temporarily allowed to continue in this partially dismounted condition. The construction of the spectrograph with its optical parts of quartz is yet to be thought out and given practical form. Then a suitable observing-house is to be provided, which I am thinking of arranging in such a manner that it will be easily transportable, in the hope that this excellent little telescope may be set up in some more suitable place than in Germany, and particularly than in the damp region of Potsdam, in order that the telescope shall be fully utilized. But the first thing will be to raise the money for this very desirable expansion of the instrumental equipment of the observatory, which in any case promises a successful result.

ASTROPHYSIKALISCHES OBSERVATORIUM,
Potsdam.

A LARGE QUARTZ SPECTROGRAPH

By PERCIVAL LEWIS

With the aid of a generous grant from the Carnegie Institution of Washington, the writer has been enabled to purchase two exceptionally large quartz prisms, with lenses of corresponding size, and the other materials for the construction of a powerful quartz spectrograph to be used for investigations of ultra-violet spectra. This instrument has been built from the writer's designs by Mr. W. R. Stamper, the mechanician of the Physics Department of the University of California. Much credit is due to him for his suggestions and skilful workmanship.

The prisms are of the Cornu type, each consisting of two half-prisms of 30° angle, of right and of left rotation respectively. Their height is 6.8 cm, and the length of face 9.2 cm. The crystal is perfectly clear and free from air-bubbles. The lenses are plano-convex, 9.2 cm in diameter, and of 1 m focal length for sodium light. They were made by A. Jobin, of Paris, who spent several months in the search for crystals of the requisite size and quality. The surfaces of the prisms are guaranteed accurately plane within one-fifth of a wave-length.

A view of the instrument is given in Fig. 2. The collimator tube, prism-box, and camera-box are in a vertical plane, to secure compactness, stability, and convenience of manipulation, the slit being horizontal. The supporting framework is of cast iron and brass, with tie-rods of iron to secure rigidity. The extreme height is 145 cm, but the collimator tube slopes downward at an angle of about 15°, so that the slit is about 105 cm above the floor, as shown in Fig. 2 by the meter rod leaning against the end of the collimator. This brings the slit into a convenient position with respect to a source of radiation placed on an ordinary laboratory table. The camera-box projects into a small cabinet protected by dark hangings, so that the film-holder may be loaded, placed in position, exposed, taken out, and the film developed without darkening the workroom.

The camera-box has a rigid framework of angle-iron, and is covered with sheet aluminum, blackened on the inside. Its axis is approximately at right angles to the collimator; but adjustment through several degrees is possible by rotating it about an axis *A* (Fig. 1) passing through the center of the prism-box. The latter has brass side-plates, built up on a cast brass bed, with a hinged top of sheet aluminum, which swings back to give access to the prisms. Each prism is mounted on a wooden block *B*, and fits snugly between two side boards of wood, with thin flanges on the lower side of each to keep the prisms from slipping out. There is no pressure whatever on the prisms. Each prism-holder is suspended on pivots *C* and *D* coinciding with the prolongations of the median lines of the prism-faces adjacent to the collimator and the camera lens respectively, these pivots being fixed to the prism-box in the case of the prism next the collimator, and to the prolongation of the sides of the camera-box in the case of the other prism. By this device the prisms are kept automatically with their effective apertures centrally situated with respect to the lenses. The adjacent angles of the prisms are only a few millimeters apart and in the line of the axis *A* on which the camera-box swings. The angular adjustment of the prisms is controlled by two screws *S* which pass up through the bed-plate and tilt the prism-holders about their axes. The lenses are fixed in position as near as possible to the prisms, and all focusing is done by displacing the slit or film-holder.

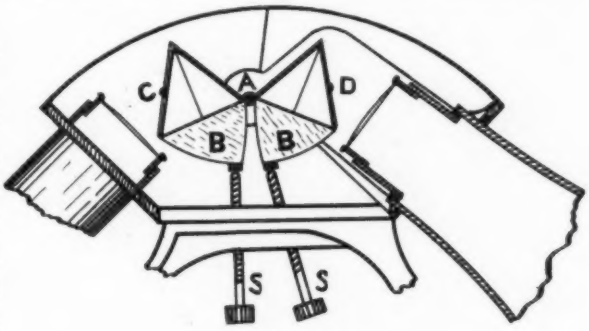


FIG. 1

The platform upon which the film-holder rests is accessible through a hinged door, which is shown open in Fig. 2. The distance of this platform from the camera lens is adjusted by a screw connected by a bevel gear with a crank behind the camera-box.

It can be set at any desired angle with the axis of the camera lens with the help of a divided circle on the outside, and clamped firmly in position. The film-holder is of wood, and is held accurately in place by two pins projecting upward from the platform, on or

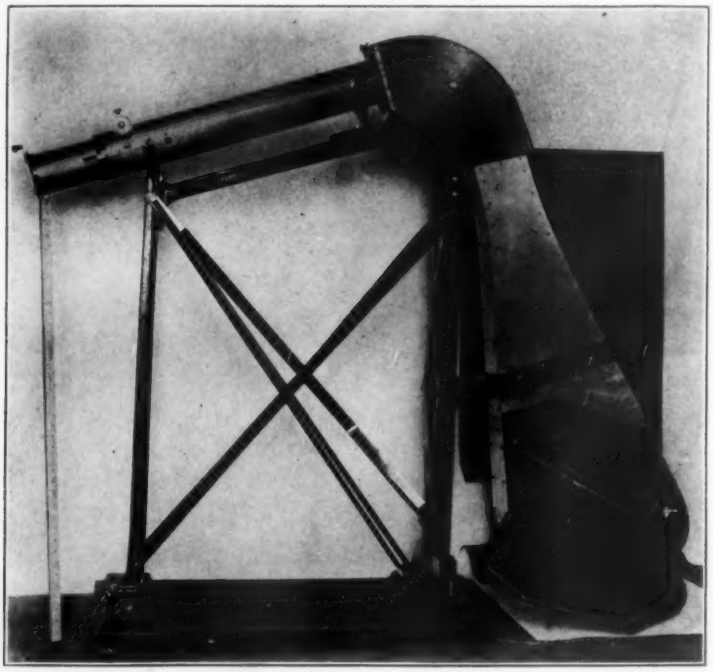


FIG. 2

from which it can easily and quickly be set or removed. The upper surface of the holder, on which the film rests, is of sheet brass, its curvature being adjustable within limits by the screws which hold it against its wooden base. The film-holder may be moved parallel to itself, for the purpose of taking several exposures on the same film, by a screw operated by a crank in the rear. The curvature of the focal surface is so great with two prisms (the radius of curvature being only 60 cm) that glass plates cannot be used. So far ordinary Eastman films have been used, cut into strips about 4 cm wide and 40 cm long, but the intention is to use stiffer celluloid plates. These films are held firmly against the upper surface

of the holder by a spring brass frame having the same curvature as the latter and kept in place by hinge-pins at one end and a spring-clip at the other.

A long series of trials showed that the best results in dispersion and definition were obtained with equal focal distances of about 91 cm for slit and film-holder. This corresponds to adjustment for a parallel beam for about λ 2600, or about the middle of the spectrum. The prisms are set for minimum deviation for a wave-length of about 2400. As shown by V. Schumann,[1] better definition throughout the spectrum is gained by setting the prisms for minimum deviation of the shortest waves observed; but it was found inadvisable to do this with two thick prisms, because the less refrangible waves then traverse the prism at such a great angle with the optic axis that perceptible double refraction occurs. In cases when the angle of incidence was 57° or more the sodium lines were seen as distinctly separated plane-polarized doublets. With an angle of incidence of 53° or 54° this effect is not observed.

Both the curvature of the focal surface and its angle with the camera axis vary with the relative focal distances of slit and camera. With one prism the angle of the film-holder with the axis is only about 26°. With two prisms, however, this angle is increased to about 47°, so that the angle of incidence on the film is much diminished, with consequent great improvement in narrowness of lines and diminution of the distorting effect due to inequalities in the surface of the film.

A trial was made of the arrangement recommended by Hartmann,[2] a half-prism being placed directly in front of each lens, so that the light enters normally on the side opposite to the hypothenuse. The second prism was placed symmetrically between the two half-prisms. The arrangement was found to be unsatisfactory when used with two half-prisms and one double prism. The dispersion was only two-thirds as great as with the ordinary arrangement (as might have been predicted by calculation), and it was necessary to place the film-holder so obliquely to the incident light that broadening and irregularities of the lines became very pronounced. With

[1] *Wiener Berichte*, **102**, 664, 1893.

[2] *Zeitschrift für Instrumentenkunde*, **25**, 161, 1905.

the two half-prisms alone the results would probably have been better.

Photographs have been obtained giving good definition throughout the range between λ 2100 and λ 6000. The length of this spectrum is about 40 cm. The spherical aberration of the lenses manifested itself in a faint nimbus around the stronger lines, observable only after overexposure. Of course, only those lines due to pencils which are parallel or which traverse the prism at the angle of minimum deviation are strictly homocentric images of the slit; the other lines are focal-line images, endowed with the defects of these images, such as a slight dissymmetry or faint "wings" on one side. Such effects are noticeable, however, only above a wave-length of about 5000. The resolving power of the system is so great and the

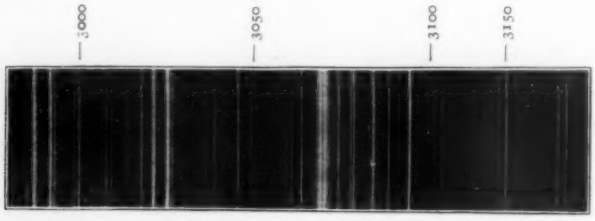


FIG. 3

lines so narrow, that these defects are evident only under a microscope even above λ 5500, and cannot seriously affect accuracy of measurement.

The details of the photographed spectra are so fine as to require magnification to bring them out. Fig. 3 is a fourfold enlargement of a small part of the bismuth and iron arc spectrum. The strong reversed line at the center is the bismuth line λ 3067.8. Although this region is at some distance from that in which the conditions for homocentricity exist (λλ 2400–2600), the lines are sharp and symmetrical. More than two hundred lines are distinctly to be seen with a microscope in this space of about 200 Ångström units. Many of the fine details are lost in the reproduction.

The dispersion in the visible spectrum is, of course, small, but in the extreme ultra-violet it exceeds that of a 15-foot grating. In the neighborhood of the D lines there are about 70 Ångström units

per millimeter; at λ 4500, about 30; at λ 3000, about 8; at λ 2700, about 5; at λ 2400, about 3; and at λ 2200, about 2. With a 15-foot grating the dispersion is about 3.7 units per millimeter in the first order.

This spectrograph also possesses great light-power, as compared with a grating. The arc spectrum of iron requires only 1 second of exposure for the ultra-violet, while for the grating half a minute or more is necessary. This instrument will, therefore, be very useful in the investigation of faint ultra-violet spectra.

Owing to the great thickness of the optical system, the absorption of the quartz becomes very noticeable at λ 2200. In using Hartmann's double-slit extra-focal method of focusing only one image of each line could be observed in this region. It was found that this image was due to the pencil passing through the thin edge of the prisms; that passing near their base was completely absorbed.

UNIVERSITY OF CALIFORNIA,
April 7, 1906.

OBJECTIVE-PRISM COMPARISON SPECTROGRAPH

By DE LISLE STEWART

The accompanying figures show an arrangement for utilizing objective-prisms for "line-of-sight" determinations. Two objectives L^1 and L^2, preferably of equal diameter and equal focal length, are mounted so that their optical axes make an angle of several degrees with each other, 15° in this case. Before each is placed an objective-prism P^1, P^2, of about 12° angle. The thick edges of these prisms face each other. When the prisms are adjusted for angle of minimum deviation, the spectrum of a star will be thrown about 7°.5 toward the central line of the apparatus. This will bring the two spectra close together on the photographic plate, $E\ F$, but in reverse order.

The plate being inclined 7°.5 to the axis of each telescope, the more refrangible rays in each case will have the longer distance to traverse before reaching the plate. Experiments made by the writer at Arequipa, with the 13-inch Boyden telescope with battery of two objective-prisms, showed that inclined plate-holders, one of 5°, the other of 10° inclination, gave a more extended region of sharp definition than when the plate was perpendicular to the telescope's axis. The focal distance was greater for rays of greater refrangibility. The mean of these two inclinations, or 7°.5, was thus used in Fig. 1.

Two smaller lenses of equal or greater focal length than the main objectives would be placed in the central line of the apparatus, one, L^3, to use as a guiding telescope, the other, a photographic lens, L^4, to give a reference image or trail of the star on the plate. Approximate positions of the lenses and prisms, as seen from the direction of the star, are shown in Fig. 2.

Flexure of the telescope tube from the great weight of prism cells and counterpoises, and the non-symmetrical form necessary, have been serious obstacles to close investigation with objective-prisms. By placing two systems in the symmetrical relation proposed, it is believed that torsion may be eliminated. Then results such as

Professor Bailey obtained for the spectroscopic binary μ^1 *Scorpii*, where both components are bright, might also be obtained with single stars showing motion.

The lenses and prisms arranged as in Fig. 1 would be firmly supported in a triangular box-shaped tube, represented in section

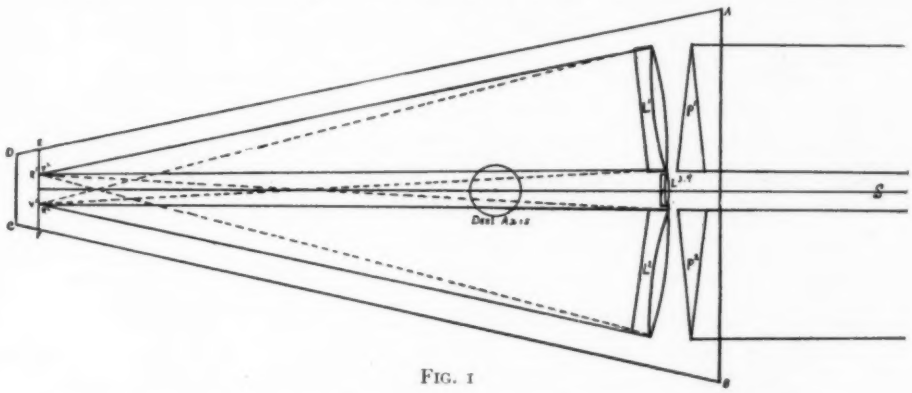


FIG. 1

by *ABCD*. This box-tube should be made of such material as to reduce variations from change of temperature to a minimum, and be so thoroughly braced as to avoid flexure. As it forms the whole telescope and not merely an eyepiece attachment, no sacrifice of weight is called for. It is intended to be bolted to the declination axis of an equatorial mounting in place of the regular telescope tube, or supported between the forks in the other style of mounting.

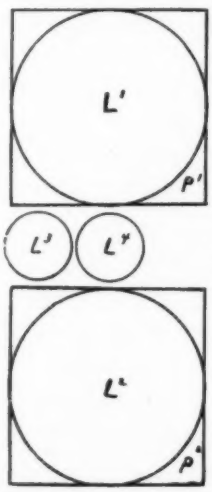


FIG. 2

In the figure the ratio of diamteter of principal lenses to focal length is large, being 1:5. It was so drawn to show how wide an angle the objectives could have and not interfere with the smaller lenses. Greater proportional focal length would have its advantages.

Experiments would show how the angle of separation should be changed to meet the conditions of the problem. Lenses 12 inches in diameter and of 15 feet focal length would allow room between them for a 4-inch auxiliary lens, if placed so that their centers

were 18 inches apart. This would mean 8° separation, and would require prisms of about 6° angle, whose minimum deviation would equal the necessary 4°. The same lenses could be used with prisms of any angle up to 25° or 30°, without losing the advantage of the inclination of the plate, or having the instrument become unwieldy through too great spread in declination. In any case, the minimum deviation of the prisms will need to equal one-half the angle of separation, which also equals the inclination of the plate to each prism-system. An increase of separation to 60° would call for 42° prisms, and would make the box-tube equilateral, thus nullifying the effects of expansion of the tube on the shifting of the spectra. Such a form would seem unmanageable unless of quite short focus, but its prisms would give large dispersion. It would hardly be possible to take full advantage of great focal length, large dispersion of prisms, and plate inclination in one instrument. Some middle course would be necessary.

In planning the instrument, its use for one star at a time was primarily considered. One *reliable* determination of a star's motion from each exposure should not be discouraging. When the problem is successfully solved for this most favorable position, then some further results might be looked for from other parts of the plate. The inclination of the plate might complicate the reductions for stars much removed in declination from the plate center.

Adjustment screws would be provided for lens and prism-cells, so that the two spectra and reference trail may be as favorably located as possible for plate measurement. This trail would be relatively stationary, while the spectra would show equal shiftings in declination, if the prism-systems were identical, or perhaps slightly unequal shiftings under actual working conditions. The trails or star-images make the negative virtually a chart-plate, whose constants may be fully determined, if necessary. These constants would serve to detect changes in focal length from temperature variations or other causes. Any shifting due to the star's motion would be doubled in quantity, and its amount would be finally determined differentially from measures of all suitable lines.

Careful "following" with lens L^3 would eliminate drift in declination, and proper width could be given to the spectra by changing

the rate of the driving-clock, or moving a right ascension micrometer-wire at a previously calculated rate.

In studying the problem it seemed essential that a form of instrument be used with which the two spectra shall be photographed simultaneously, so as to eliminate or equalize the differential effects of refraction, change in temperature, and flexure. This also means that the exposure time will be reduced one-half. The readjustment of an essential part of the spectrograph between the exposures, as the reversal of a prism or the plate, might make the results questionable and should be avoided. This calls for a duplication of some parts. A study of the peculiarities of any prism or lens may thus be made by interchanging its place.

Professor E. B. Frost, to whom my thanks are due for very kindly suggesting some of the difficulties of the problem, states that he would expect the probable error of a determination with this apparatus to be not less than 20 kilometers.

However, the plan suggested seems to meet many of the conditions of the problem. As actual work on the apparatus progressed, ways, optical and mechanical, might be found for overcoming the remaining obstacles.

CINCINNATI OBSERVATORY,
May 4, 1906.

SUN-SPOT LINES IN THE SPECTRA OF RED STARS[1]

By George E. Hale and Walter S. Adams

In a paper on "The Spectra of Stars of Secchi's Fourth Type" (*Publications of the Yerkes Observatory*, **2**) the following statement appears on p. 129:

> The possibility that spots like those on the Sun may form a characteristic feature of fourth-type stars is strongly suggested by the evidence which we have accumulated (p. 123). It is hardly necessary to say, however, that much more evidence in this direction is needed. In view of the ease with which sun-spot spectra may be observed with instruments of moderate size, our knowledge of the widened lines is surprisingly meager. Much systematic work on spot spectra must therefore be done before the data desired for a thorough study of the question will become available. If the lines widened in sun-spots are to be regarded as characteristic of fourth-type stars, they seem to be equally characteristic of stars of the third type. This fact will permit a rigorous test of the identification of the lines to be made, since several stars bright enough to be photographed with very high dispersion occur among the stars of the third type.

Dr. Walter M. Mitchell has recently taken up this subject,[2] with the aid of his excellent observations of spot spectra, made with the Princeton refractor. He finds it almost impossible to make a satisfactory comparison of fourth-type and spot spectra, but concludes that they are not similar and that many spot lines are not represented in these stars.

The view suggested in the paper first quoted was not that fourth-type and spot spectra are similar, but rather that there was reason to suspect the presence in these stellar spectra of a considerable number of characteristic spot lines, which, if present, would presumably be due to large spots similar to those on the Sun. The presence in fourth-type spectra of strong lines and bands, such as the carbon flutings, which are known to be unaffected in sun-spots, is in no wise opposed to such a view. Indeed, these flutings are merely what may be expected to appear in a star like the Sun when it reaches an advanced stage of development.

The possibility, however, of comparing Dr. Mitchell's spot lines

[1] *Contributions from the Solar Observatory*, No. 8.

[2] *Astrophysical Journal*. **23**, 211, 1906.

with those of the fourth-type stars throws new light on the subject, though it must remain in an unsatisfactory state until better photographs of fourth-type spectra can be obtained. Our five-foot reflecting telescope, when erected on Mount Wilson and provided with a suitable spectrograph, should be an ideal instrument for this research. At present we are able to contribute only such results as have been obtained with the Snow telescope, which is not adapted for work on stars as faint as those of the fourth type. So far as these latter stars are concerned, we limit ourselves for the present to recalling the probability that some of the missing spot lines in their spectra may be covered by bright lines. The rest of the evidence must stand as it is until better data become available.[1]

In order to secure material for an adequate determination of the wave-lengths of the lines in the spectrum of a third-type star, a plate of *α Orionis* was taken with the Snow telescope. The apparatus employed was a 64° prism of dense flint glass belonging to the five-foot spectroheliograph, used in conjunction with two visually corrected lenses of 5 inches (12.7 cm) aperture and 149 inches (3.78 m) focal length. The prism was sufficiently high to admit the full vertical aperture of the lenses, but in a horizontal direction could utilize a beam only 2.25 inches (5.72 cm) in width. The prism was set at minimum deviation for λ 5600. The whole instrument was inclosed in a box on the large pier inside the constant-temperature room of the Snow telescope house, and its temperature was accurately controlled by an ether regulator acting on a relay in such a way as to open and close automatically the circuit of heating coils inside the box.

It had been intended to expose the plate for two nights, but on the second night clouds cut the exposure short at the end of two hours.[2] The total exposure time was about seven hours, and the plate is not sufficiently strong to be of the best quality. It is, how-

[1] Of the four titanium lines referred to by Dr. Mitchell (p. 218), two are not in the "yellow region" to which my remark was limited (λ 5899.5 being beyond the reach of our three-prism plates); λ 5219.8, which was by some accident omitted from our tables of widened lines in spot spectra (*Contribution* No. 5), may be covered by a bright line in the stars (see p. 103 of our memoir); and λ 5471.4 is shown by our photographs to be one of the less conspicuous spot lines, ranging in intensity from 1 to 2.

[2] The rainy season prevented further work on the spectrum of *α Orionis*.

ever, measurable from about λ 5400 to λ 5700, and the results given in the table below are derived from it. The linear scale at λ 5400 is about 1 mm = 10 Ångströms.

The estimates of intensity are based upon Rowland's scale and are subject to some uncertainty, owing to the character of the plate. Reference lines were secured by taking certain of the lines referred to by Keeler as of the same intensity in the star and in the Sun, and using Rowland's intensities for these.

RADIAL VELOCITY OF α *Orionis*

λ in Sun	Intensity in Star	Intensity in Sun	Intensity in Spots	Velocity
5405.989	8	6	8	+53.58
5434.740	7	5	6	55.34
5447.130	8	6	8	52.19
5497.735	8	5	6	51.65
5501.683	6	5	5	54.34
5507.000	6	5	7	54.23
5569.848	5	6	6	51.75
5573.075	7	6	6	55.69
5576.320	4	4	4	55.44
5586.991	5	7	8	54.74
5624.769	4	4	4	54.38
5709.601	8	5 5	7 5	52.57
			Mean	+53.82
			Reduction to Sun	−27.16
			Radial velocity	+26.7 km

The wave-lengths given in the following table have been corrected for radial velocity:

LINES IN THE SPECTRUM OF α *Orionis*

λ in *	λ in ⊙	Element	Int. in *	Int. in ⊙	Int. in Spots	Remarks
5393.36	5393.38	*Fe*	6	5	5-6	
5394.88	5394.84 .91	*Mn*	7	1 1	4	
5407.62	5407.59 .69	*Mn*	3	0 0	2-3	
5409.95	5410.00	*Cr*	6	4	6	
5418.99	5418.98	*Ti*?	5	1	n.c.	
5420.59	5420.51 .61	*Mn*	4	oN oN	3	
5426.50	5426.47	——	5	00	2	*Ti*. Hasselberg has 5426.48
5432.96	5432.75 33.16	*Mn* *Fe*	5	1 2	3 n.c.	
5436.85	5436.80	——	2	1	2	Possibly *V*

LINES IN THE SPECTRUM OF α *Orionis—Continued*

λ in *	λ in ⊙	Element	Int. in *	Int. in ⊙	Int. in Spots	Remarks
5442.60	5442.63	*Cr*	2	oo	o	
5460.74	5460.72	——	5	oo	2-3	*Ti*. Hasselberg has 5460.72
5470.88	5470.80	*Mn*	4	o	2-3	
	.88			o		
5490.62	5490.37	*Ti*	9	o	3	
	90.90	——		o	1-2	*Ti*. Hasselberg has 5490.88
	91.04	——		ooo	1-2	
5493.67	5493.71	*Fe*	3	1	1-2	
5504.12	5504.12	*Ti*	2	o	1	
5512.92	5512.47	*Fe*	8	1	n.c.	
	12.74	*Ti*		2	3	
	13.20	*Ca*		4	n.c.	
5514.68	5514.56	*Ti*	7	2	2-3	
	.75	*Ti*		2		
5517.00	5516.95	*Mn*	7	o	2	
	17.03			o		
5528.65	5528.64	*Mg*	7	8	n.c.	
5530.98	5531.00	*Ti*	2	ooN	o-1	
33.05	5532.97	——	6	1	n.c.	
	33.09	——		o	n.c.	
5535.65	5535.64	*Fe*	8	2	3-4	Rowland and Harrison have *V* line at 5535.66
	.78	——		o		
5537.96	5537.93	*Mn*	3	oo	2	
	38.02			oo		
5546.82	5546.73	*Fe*	5	2	2-3	
	47.22	*Fe, V*		1	1-2	
5565.77	5565.70	*Ti*	5	oo	2	
5582.19	5582.20	*Ca*	5	4	5	
5584.77	5584.73	——	2	ooo	oo	*V*. Rowland and Harrison have 5584.74
5594.72	5594.69	*Ca*	5	4	5	
	.88	*Fe*		1	n.c.	
5598.67	5598.52	*Fe*	8	1	n.c.	
	.71	*Ca*		4	5	
5626.24	——	——	3	——	1	*V*. Rowland and Harrison have 5625.27
5627.85	5527.86	*V*	4	oo	2-3	
5641.67	5641.67	*Fe*	3	2	n.c.	
5644.30	5644.26	——	3	oo	2-3	
	.37	*Ti*		o		
5664.86	5664.80	——	4	ooo	o	
5668.63	5668.59	*V*	6	coo	1	
5675.60	5675.65	*Ti*	6	2N	2-3	
5682.86	5682.87	*Na*	7	5	7	
5698.79	5698.75	*V*	7	1	3-4	
5700.53	5700.51	*Cu?*	3	oo	2-3	Probably *Sc*
5703.75	5703.80	*V*	5	1	3	

The intensities of the following iron lines, which could readily be identified from their coincidence with lines in the comparison spectrum, were also noted. They were not of suitable quality for the determination of radial velocity and so were not measured.

Line	Intensity in Star	Intensity in Sun	Intensity in Spots
5397·34	10	7	9
5404·36	7	7	7–8
11.11	4	4	n.c.
15.42	6	5	n.c.
24.29	6	6	n.c.
29.91	8	6	8
45.26	5	4	n.c.
55.67 .83	6	6	n.c.
5615.52 .88	9	8	n.c.

The abbreviation "n. c." denotes that the line is unaffected.

A summary of these results gives the following values for the difference between the relative rise of intensity in *α Orionis* and spots:

RISE IN INTENSITY

	Spots	*α Orionis*	*α Orionis* – Spots
Vanadium	2.5	5.0	2.5
Titanium	1.5	4.2	2.7
Manganese	1.3	3.7	2.4

The approximately constant value of *α Orionis* – spots indicates the great similarity in the behavior of these elements in spots and in the star.[1]

Of the individual lines affected probably the most interesting case is λ 5626.24. This line does not appear in Rowland's Preliminary Table, but is prominent in spots. It is almost certainly due to vanadium, which has a line of considerable intensity at λ 5626.27. Two other vanadium lines, λ 5584.73 and λ 5668.59, of intensity ooo in the Sun, and a third of intensity oo, are all important lines in the star. The cumulative evidence afforded by the

[1] In comparison with these values we have for ten lines of iron affected in spots and measured in *α Orionis* the following values of the rise in intensity as referred to the Sun:

Spots	*α Orionis*	*α Orionis* – Spots
1.1	1.1	0.0

behavior of these lines as to the similarity of the spectra of stars and spots is extremely strong, quite apart from the similar testimony afforded by the other lines of this element, as well as those of titanium and manganese. The last-named element, as was shown by Mitchell and confirmed by the observations of Hale and Adams, is one of the most prominent in the spectrum of spots.

Though it has not been possible, on account of the character of the plate, to measure all the lines which are present, the list given above affords very strong evidence of the general agreement between the spectrum of *α Orionis* and that of sun-spots. In the region covered, λ 5393 to λ 5704, there are but four spot lines of intensity greater than 1–2 on Rowland's scale that have not been measured in *α Orionis*, and these are all present but too diffuse for measurement. Of the fainter lines, several are practically obliterated in the band, the more refrangible edge of which falls at λ 5447.

In a comparison of the stellar lines with those affected in spots the greatest interest naturally attaches to the lines of the three elements most prominent in the latter—vanadium, titanium, and manganese. Including the almost certain identifications with the lines given in Rowland and Harrison's table of the arc spectrum of vanadium, we find in the region under discussion six lines with a mean rise in intensity in spots, as compared with the Sun, of 2.5. All of these lines are found in *α Orionis* and show a mean rise in intensity of 5.0. Identifying the titanium lines in a similar way with those of Hasselberg's table, we find nine lines due solely to titanium which are affected in spots and are of intensity greater than 1–2. One of these is not measured in the star, and three others blend with adjoining lines. The remaining five have a mean rise in intensity in spots of 1.5, and in *α Orionis* of 4.2. In addition, there are two lines of mean intensity 0.8 in spots, which are measured in *α Orionis*. Of manganese there are eight lines affected in spots. Of these one is not measured in *α Orionis*, and another forms a blend. The remaining six show a mean rise in intensity in spots of 1.3, and in *α Orionis* of 3.7.

SOLAR OBSERVATORY,
Mount Wilson, May, 1906.

Minor Contributions and Notes

NOTE ON THE *ALGOL* SYSTEM

In the case of variables of the *Algol* type it is well known that an upper limit to the mean density of the system can be found.[1] Also in the case of *Algol* itself, where we know the velocity of one component, the dimensions of the system can be calculated if we make such an assumption as that the densities of the two components are equal;[2] but it does not seem to have been remarked that without any such assumption a lower limit to the diameters can be obtained, and also upper limits to the density of each component separately.

If we call

a, a', the radii of the two components,
r, r', the radii of their orbits,
d, d', their densities,
T, the period of revolution,
t, the duration of light-variation,
γ, the constant of gravitation,
D, the mean density,

then, calculating for a circular orbit and central eclipse, which will be sufficiently accurate throughout this paper, we find

$$D=\frac{3\pi}{\gamma T^2}\cdot\frac{(a+a')^3}{a^3+a'^3}\cdot\frac{1}{\sin^3\frac{\pi t}{T}}.$$

If we put

$$a'=0.764\,a,^3$$
$$t=9^h\,20^m,$$

we find

$$D=0.129.$$

We have also $a+a'=(r+r')\sin\frac{\pi t}{T}$, and if we write

$$d'=nd,\quad a'=ka,\quad (k=0.764)$$

[1] Alexander Roberts, *Astrophysical Journal*, **10**, 308, 1899; H. N. Russell, *Ibid.*, **10**, 315, 1899.

[2] H. C. Vogel, *Astronomische Nachrichten*, **123**, 289, 1890

[3] E. C. Pickering, *Proc. Amer. Acad.*, **16**, 27, 1881.

we can deduce

$$a = r\frac{nk^3+1}{nk^3(k+1)} \cdot \sin\frac{\pi t}{T},$$

$$d = D\frac{k^3+1}{nk^3+1},$$

$$d' = D\frac{n(k^3+1)}{nk^3+1}.$$

Consequently we find that a is a minimum when n is infinite and that then

$$a = 0.234\, r.$$

Hence, r being a million English miles, 468,000 is a lower limit to the diameter of the bright component. There is no upper limit; the smaller n is, the larger must the diameters be, supposing, of course, the eclipsing body to be always opaque and faint in comparison with the bright one.

Again, d is a maximum when $n=0$, and then $d=0.186$; d' is a maximum when n is infinite, and then $d'=0.418$; the maximum of d occurring when $d'=0$ and conversely.

While the ratio of the densities is not likely to be a very large number, yet, on the other hand, it may differ considerably from unity, and the following results have been calculated for densities of the satellite ranging from four times to one-fourth that of the primary:

$\frac{d'}{d}$	$\frac{a}{r}$	$\frac{r'}{r}$	d	d'	m	m'
4	0.36	0.56	0.07	0.27	0.029	0.052
2	0.50	1.12	0.10	0.20	0.107	0.096
1	0.76	2.24	0.13	0.13	0.51	0.23
0.5	1.28	4.48	0.15	0.08	2.84	0.63
0.25	2.33	8.96	0.17	0.04	19.2	2.14

The second column practically gives the radius of the larger body in millions of miles. The last two columns give the masses of the two in terms of the Sun's mass.

A much greater diameter and smaller density are given here for the case of equal densities than are given by Vogel. This is, of course, due to taking t as $9^h\ 20^m$ instead of $6^h\ 30^m$.[1]

R. J. A. BARNARD.

MELBOURNE.

[1] See Vogel, *loc. cit.*

LETTER FROM PROFESSOR CALLENDAR

With reference to my letter of October 26, 1905, which appeared in the March issue of your *Journal*, I have since had the pleasure of a personal interview with Mr. G. T. Walker, which has resulted in a simple explanation of the difficulty experienced with the sunshine receiver in question. Mr. Walker informs me that there was a good deal of condensation inside the cover of the receiver at the time when he saw it, which would naturally render the results unreliable, but that there was no drying material in use at the time, and that neither he himself nor the observer in charge was aware of the necessity of employing drying material to prevent condensation. It appears on investigation that the instrument company which supplied the receiver, by some accidental oversight, owing to the different parts of the apparatus having been ordered and supplied at different times, omitted to send specific instructions with regard to the necessity of employing drying material in the receiver. I greatly regret that this omission did not come to my knowledge sooner. but I had no personal knowledge of the transaction, and the instrument company had some difficulty in finding the records of the correspondence, etc., relating to the subject, as the instrument was supplied so long ago. Mr. Walker assures me that he has no reason to believe that the method would not give good results if the receiver were kept dry, but he agrees with me that the hermetically sealed type would be more suitable for use in damp climates, as requiring less attention; though even in this case it is necessary to clean the exterior of the receiver at frequent intervals, if exposed to dust or damp. As several of these instruments are now in use in various parts of the world for investigating possible variations of the solar radiation, it is important to draw attention to the necessity of these precautions, as other observers may have experienced similar difficulties.

H. L. CALLENDAR.

ROYAL COLLEGE OF SCIENCE, LONDON, S. W.,
April 3, 1906.

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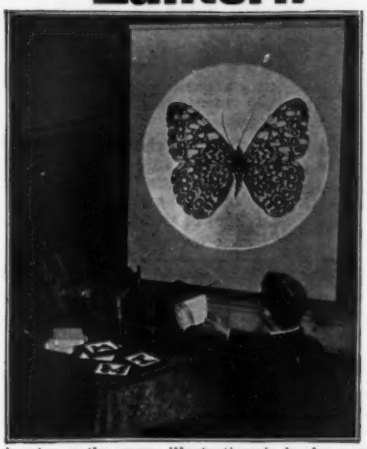

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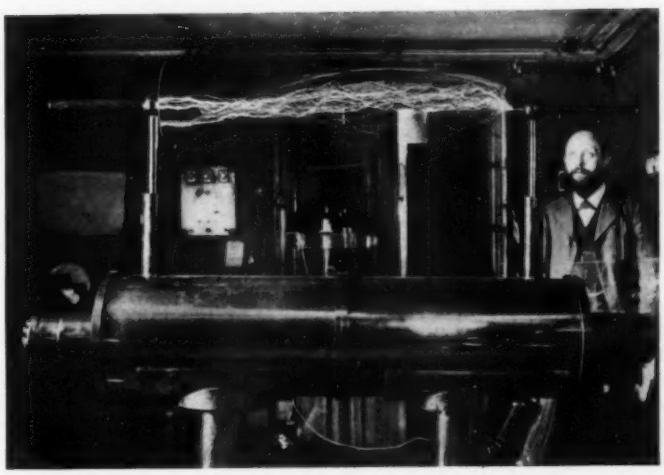

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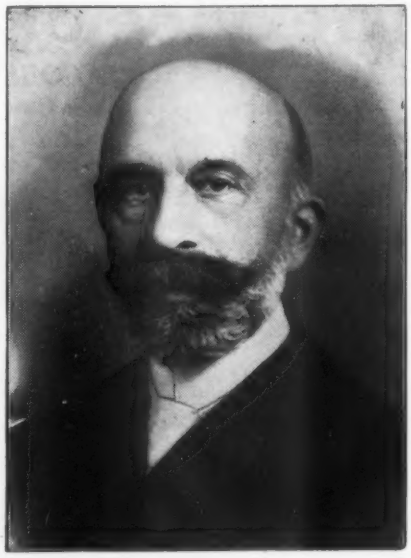

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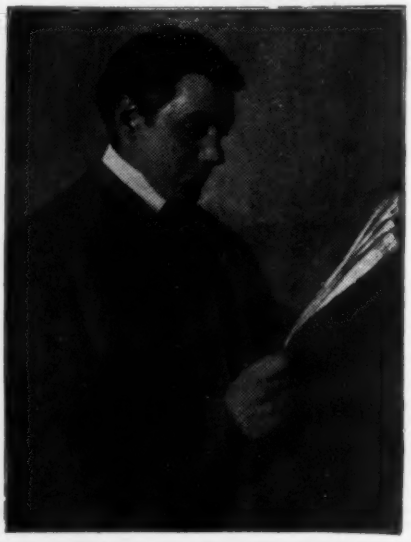

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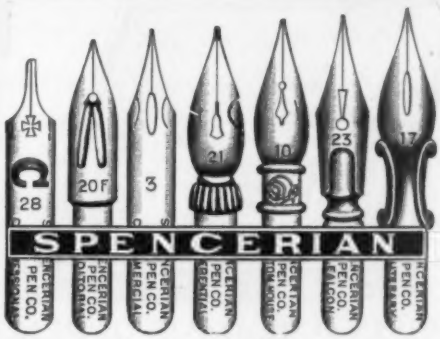

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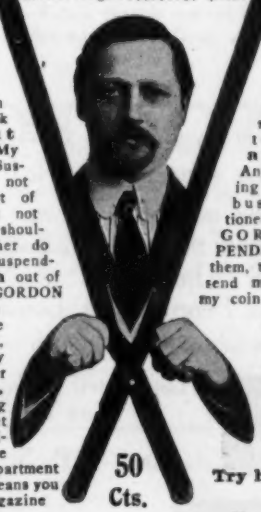

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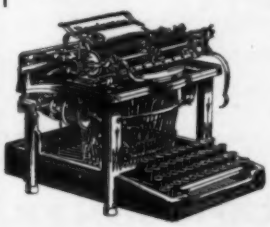

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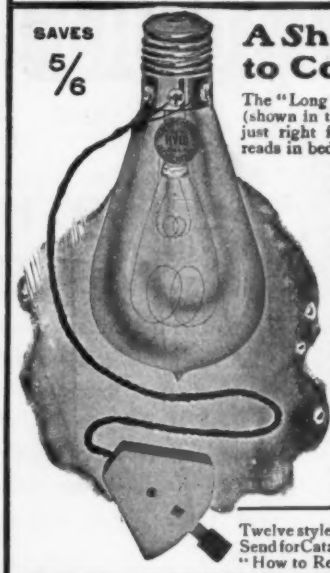

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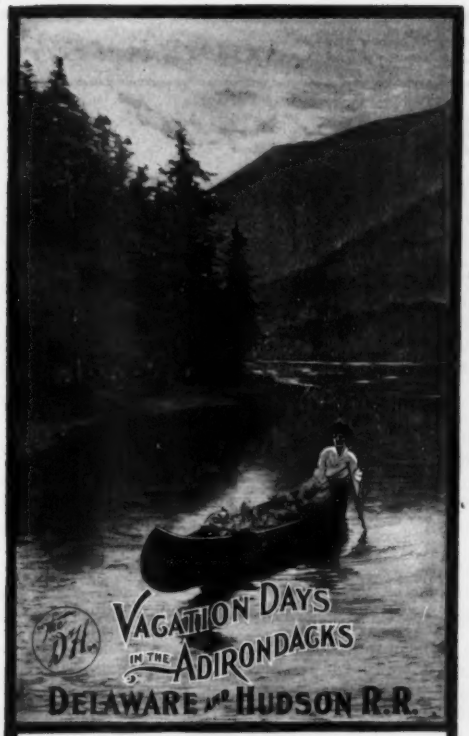

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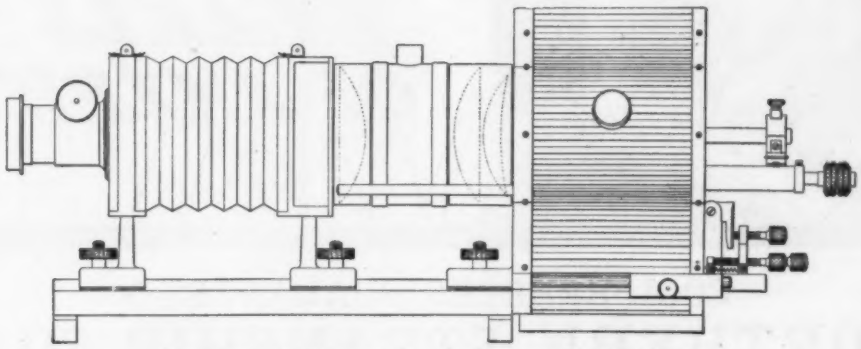

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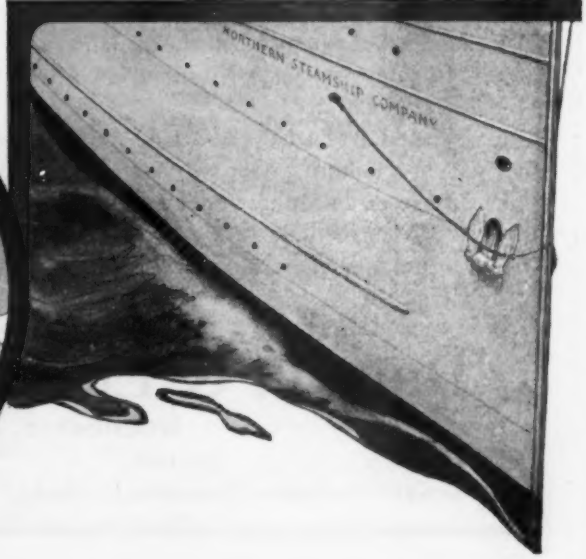

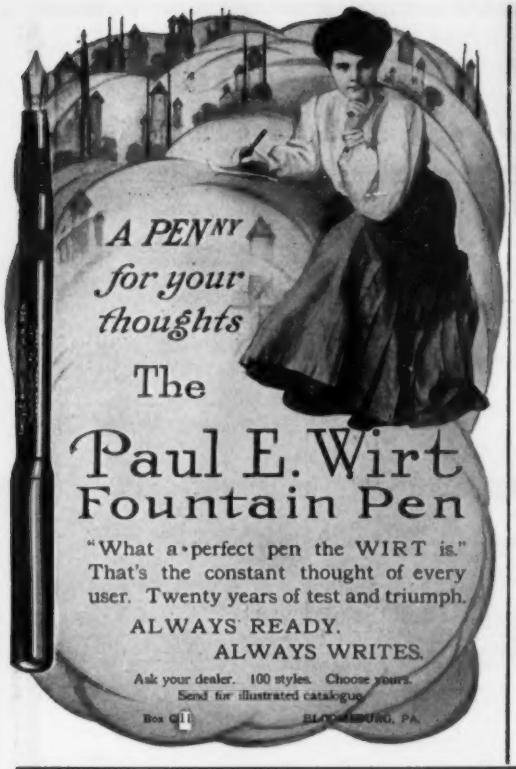

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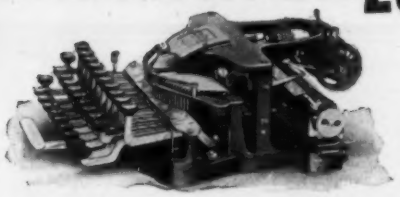

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